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THE DEVELOPMENT OF AN APPROACH AND DECISION SUPPORT TOOL TO INFORM SUSTAINABLE ROOF SELECTION

Volume 1 of 2 (Main Body)

Philip Roy Hampshire

A Thesis Submitted for the Degree of Doctor of Engineering

University of Bath

School of Management

Date: February 2015

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i. Abstract

Despite the importance of roofs, improved roof selection has not been explored in significant depth. Therefore this research explores the possibilities that roofs offer to improve the value and sustainability of buildings. It is concerned with the roof as a system, explicitly connected with the building and their impacts on wider society.

This research, develops and tests techniques to better understand what constitutes value and sustainability for a building project's context through action research. The sustainability and value themes output through the use of such techniques are then considered as a basis for the selection of roof attributes through Keeney's value focused thinking approach.

Once the roof performance attributes have been established, designers and clients then require quantitative data to decide which roof type represents the highest value / most sustainable option. Thus the research also collates and maps peer reviewed quantitative performance data on the performance of roofing systems in relation to climate type as well as providing information from leading modelling packages for different roof options. An approach for selecting the most appropriate data is then developed. This allows the practitioner to be able to access reliable peer reviewed information and utilise leading modelling techniques to quickly gain information regarding the performance of various roof systems for use in the project context.

An approach is developed to bring this information together with the important sustainability considerations for the project to inform sustainable roof selection. This combines the different types of roof performance with the relevant decision attributes early in the design process, to provide insight into which roof option represents the best overall economic, environmental and social value and therefore the most sustainable roof option.

The primary contribution to knowledge presented in this thesis is the development of a pragmatic realist approach to sustainable roof selection.

ii. Researcher context

All the research described in this thesis has been undertaken in the context of an engineering consultancy, Buro Happold. Buro Happold is an international engineering consultancy providing innovative and holistic skills across the built environment. The company has over 1,400 staff and currently works on building, masterplanning and consultancy projects all over the world. The approaches and techniques applied and developed through this research have been informed by and used in this context. They have had to take account of the politics of the project arena and be suitable for application in the time frame of the design process, which is typically short when compared to policy planning and implementation.

The author joined Buro Happold's Sustainability Team as a Research Engineer after graduating with a first class degree in Civil Engineering from the University of Bristol. This encompassed a wide range of topics from structural engineering to research projects looking at ways to educate engineers in sustainability. During his time conducting the research outlined in this thesis he has worked on a wide range of projects, from individual building systems to large scale masterplans. His work has focused on stakeholder engagement, decision making, roof selection, sustainability framework development, environmental modelling and the design of renewable energy systems. His time has been spent undertaking both project and research work that aligns with client needs. The final product is applied academic research that is suitable for use on real world projects.

In addition to working at Buro Happold on live projects and undertaking the research outlined in this thesis, the researcher has also taken several masters level modules at Bath University and the University of Bristol which is a requirement of the EngD in Systems Programme. These modules include:

- HR and Organisational Design
- Introduction to Systems
- Sustainable Systems
- Programme Management and Research Methodologies
- Mathematics for Systems
- Financial Management
- Advanced Systems
- Integrating Engineering and Management Systems
- Commercialisation of New Technology
- Technology Strategy and Organisation

The researcher scored an average module mark equivalent to a distinction.

The author is currently a senior sustainability consultant at Buro Happold. He has strong links with the Universities of Bath and Bristol. He is a guest lecturer on Sustainable Building Design at the University of Bristol and has also lectured students at the Schumacher Institute. He has also supervised undergraduate research projects and has won research funding to support undergraduate researchers.

iii. Acknowledgements

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vii. Acronyms

Term	Definition
AHP	Analytic Hierarchy Process
AR	Action Research
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BIPV	Building Integrated Photovoltaics These are photovoltaics that replace conventional building elements such as the roof, facade or skylights.
BREEAM	Building Research Establishment Environmental Assessment Method
BUR	Built-Up-Roof
CABE	Commission for Architecture and the Built Environment
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CIBSE	Chartered Institute of Building Services Engineers
CBA	Cost Benefit Analysis
CVM	Contingent Valuation Method
DQI	Design Quality Indicator
DST	Decision Support Tool
EAM	Environmental Assessment Method
EPC	Extended Peer Community
EF	Ecological Footprint
FSSD	Framework for Strategic Sustainable Development
kWh	Kilo-watt hour
LCA	Life Cycle Analysis
LCC	Life Cycle Costing
LEED	Leadership in Energy and Environmental Design
MCA	Multi Criteria Analysis
MCDA	Multi Criteria Decision Analysis
NGO	Non-Governmental Organisation
NPV	Net Present Value
POE	Post Occupancy Evaluation
PNS	Post Normal Science
PV	Photovoltaic
PSM	Problem Structuring Methods
RIBA	Royal Institute of British Architects
SAST	Strategic Assumption Surfacing and Testing
SI	Sustainability Indicator
SMART	Simple Multi-Attribute Rating Technique
SMARTS	Simple Multi-Attribute Rating Technique (with) Swings
SMARTER	Simple Multi-Attribute Rating Technique Exploiting Ranks
SODA	Strategic Options Development and Analysis
SRI	Solar Reflective Index

Term	Definition
SSM	Soft Systems Methodology
SUDS	Sustainable Urban Drainage Systems
SVS	Schwartz Values Survey
TSN	The Natural Step
UHI	Urban Heat Island
VALID	Value In Design
VFT	Value Focused Thinking
VBA	Visual Basic for Applications
WLV	Whole Life Value
WTA	Willingness to Accept
WTP	Willingness To Pay

viii. Executive summary

The functions that a roof provides are wide ranging and include symbolic, practical, financial and aesthetic benefits. It is also key in satisfying the key physiological need of shelter. The contribution of the roof in the construction of any building project is all-embracing, and it is largely undervalued. The roof is fundamental to the purpose demanded of all buildings, i.e. their protective function. It can also provide an excellent medium for the designer's aesthetic and technical skills. Despite all this is it is rarely an element of major consequence in the overall compilation of costs and is often the subject of merciless "value engineering" (Coates, 1993a).

Unfortunately, roofs are often overlooked as space that can be designed into an environmental amenity for buildings. If the roof surface can be transformed into useful space, the building becomes economically and functionally more efficient and can have a more benign effect on the surrounding landscape (Carter and Keeler, 2008). Roofs can reduce environment impacts of buildings and even improve the biodiversity of the site by providing habitat replacement (Newton et al., 2007). Therefore well designed and selected roofs present the possibility of not only being 'benign' to the environment, but actually providing positive environmental, social and economic benefits. It is for this reason that improved roof design and selection offers a high leverage solution in developing a more sustainable built environment.

Despite the importance of roofs, improved roof selection has not been explored in significant depth. Therefore this research explores the possibilities that roofs offer to improve the value and sustainability of buildings and for the built environment as a whole. It is concerned with the roof as a system, explicitly connected with the building.

This work employs an action research methodology to develop an approach to sustainable roof selection and accompanying decision support tool to consider value and sustainability considerations analytically. This aligns the performance of roof systems with the softer sustainability and value attributes of project stakeholders to facilitate better informed, higher value and more sustainable roof choices.

Data collected through surveys and workshops suggests that an approach developed to quantify the values of project stakeholders could be useful in defining the requirements and understanding what factors the stakeholders consider sustainable and high value. This values based approach can help align the design decisions with the thoughts of the project’s stakeholders. The approach has been demonstrated to be effective at engaging stakeholders in an open and transparent way and in providing a common language from which the design can proceed. This information and shared understanding can collectively be used to inform roof selection and other project choices.

Once the criteria for decision making have been established, designers and clients require quantitative data to decide which roof type represents the highest value / most sustainable option. Again this information has to be context specific with respect to climate of the site and the roof build-up. For consultancies designing buildings in numerous countries with significantly different climates, collating this information for individual projects can be problematic. This is due to the fragmented and case specific nature of the information. Thus the research also provides an approach to collating and mapping peer reviewed quantitative performance data on the performance of roofing systems in relation to climate type as well as providing information from leading modelling packages that account for the regional context. This provides an approach that enables the practitioner to be able to access reliable peer reviewed information and utilise leading modelling techniques to quickly gain information of roof systems for the project context.

The research develops an approach and prototype decision support tool to inform sustainable roof selection that integrates objectives developed by stakeholders with quantitative performance information. Initially this helps provide a better understanding of what constitutes sustainability value for the project’s stakeholders. Then, through easily accessible and reliable performance data, along with consideration of less tangible but important aspects of roof selection, designers will be able to employ data that can be used to inform high value and sustainable decision making. The data is then considered in parallel to roof sustainability objectives through the specific multi-attribute rating technique which allows scoring of the alternatives based on weights and also the consideration of uncertainty and risk. The benefits for the practitioner is appropriate and context specific roof performance data to support decision making with respect to roof selection. The outcome of the work is the ability to better demonstrate how more sustainable roofs provide value in line with the project context.

1. Introduction

1.1 Introduction

This section provides an overview of the background and research problem and the structure of the thesis. The various parts are then summarised briefly. The section also details the contributions to knowledge and the impact of the research.

1.2 Background and research problem

Buildings are responsible for significant environmental impacts through their construction, use and demolition. Sustainable building design and construction approaches can help to reduce these environmental impacts and also improve the social and economic viability of buildings.

There are a vast number of technologies, systems and methods that can be applied to create a more environmentally sustainable building. However, often there is insufficient data to be able to make comparisons and also a lack of a comparison system to be able to put different data into context.

There are also many environmentally focused assessment systems for buildings. However, these are typically limited in scope, not designed for a specific context, and not utilised to structure and inform decision making on projects. Therefore this research considers two areas. The first of which is how can sustainability be defined for a particular project context, including social and economic aspects which are typically not considered in traditional environmental assessment frameworks. Secondly, it aims to provide engagement tools to define the sustainability objectives for a project.

Maslow's (1943) Hierarchy of Needs, shows shelter to be important in satisfying the most basic physiological need. The roof satisfies this fundamental human need – it protects us from rain, wind and cold. The roof is particularly important in this respect because it has the highest exposure to the elements of any of the building facades. It is also often a significant proportion of the building envelope and consequently it is a major surface for heat transfer and water runoff, increasing the buildings energy requirements and runoff contribution. Consequently roofs contribute significantly to the environmental problems and therefore their improvement offers significant potential in reducing these impacts.

Roof design and selection varies based on a number of factors, including cost, practicality and architectural design. Roofs can have high environmental impacts due to their poor performance characteristics through the design life of the structure. However roofs can also be useful for reducing the environmental impact, through providing rainwater collection, reducing energy consumption, offering a location for solar panels, improving biodiversity, providing amenity space on top of a building, etc.

The aims of the research are to develop an approach to define the key sustainability objectives for a building project. Then to develop an approach and prototype roof decision support tool to inform sustainable roof selection, which based upon the building objectives can help inform the selection of the most sustainable roof option in relation to the building.

As the roof has a large influence on any building project but little consideration has been given as to how the decisions that lead to more sustainable roof selection should be made, this will be the broad area of focus for this research. The specific research questions and aims are justified and defined in the next section.

1.3 Structure of the thesis

The thesis is structured as shown in Figure 1—1. The thesis has two main parts. The methodology applied and the specific methods used are outlined in both parts. The two parts are then covered and discussed in isolation for their merits.

Further discussion is then common to both parts and explains how they could be synthesised to provide context specific roof decision making. Common next steps are then defined through which the work as a whole could be further developed.

Introduction: Overview of the thesis.

Literature Review: Overarching description of philosophy used and methods applied.

Research Approach and Strategy: Overarching description of philosophy used and methods applied

Part 1: Developing approaches to defining sustainability and value

Part 2: Developing approaches to sustainable roof selection

Conclusions: In relation to both parts of the research

Figure 1—1 Overall structure to thesis

The reason for this is that the project level sustainability objectives can be defined independently to assessing the performance of various roof system types in relation to the objectives defined.

1.4 Literature review

A review of the literature is broken down into three key areas which cover:

- **Sustainability for building projects:** This aims to give context to the research and the difficulties of defining, measuring, assessing and delivering sustainable development. It covers the concepts of sustainability and sustainable development to provide context. A review of techniques used to assess the sustainability of buildings is then considered and their strengths and weaknesses summarised. Their changing roles are discussed and future developments outlined. Parallels are then drawn between the concept of sustainability and other complex, value-laden concepts, such as value in the construction industry. Then the challenges of the design process are considered. The literature review ends summarising the gaps in the research.

- **Sustainable roof selection:** This section focuses in more detail on roof design and selection, beginning by considering the definition and function of a roof and then why the roof is important from a sustainability perspective. A brief history of roofs is given and explored, and how the need has arisen for improved methods of selecting between roof options to reflect current sustainability issues. The review then covers a variety of roof systems that are generally discussed in the literature for their sustainability credentials, and also reviews some commonly used environmental assessment methods to define typical objectives for consideration in sustainable roof selection. Then previous work in the field of roof selection and decision making is reviewed. The literature review is concluded by summarising these areas of further work required to inform the development of research questions.
- **Identifying decision support methods for complex contexts:** The aim of this literature review is to find techniques which may be applicable, for application in this research, from other fields and address some of the limitations in building environmental assessment methods detailed in the first part of the literature review.

1.5 Overarching research approach and strategy

The overarching research philosophy is based on a pragmatic realist stance, and in doing so utilises both deductive positivistic approaches and interpretivist approaches seeking to combine them in complementary ways. A mixture of research strategies make up a multi-method approach. However, the first Part of the research seeks to develop techniques which addresses some of the gaps in the current approaches to the definition of sustainability in the construction industry through action research. This involves the use of a number of data collection methods, including sampling, secondary data, observations, workshops and questionnaires. The strategies used are explained in more detail in the research approach and strategy section, and also in further depth in the relevant parts of the thesis.

1.6 Part 1: The development of approaches to engage stakeholders in defining sustainability and value for projects

This part has the overarching research objective, ***"to develop and test approaches to improve the elicitation of what represents sustainability and value in the project context".***

A literature review is initially undertaken to understand the current gaps in the research and areas where improvements can be made. This first looks into the history of sustainability and sustainable development, and different concepts and definitions that have emerged over the past 50 years. Ways of defining, measuring and assessing sustainability are then considered for the design and construction context. These have influenced the philosophical stance taken and the approaches used.

Similarities are then drawn between the concepts of sustainability and value. The logic behind considering these in parallel is then argued. This section is concerned with structuring the decision making objectives and is based on the philosophy of value focused thinking first described by Ralph Keeney. In essence it looks to first define what are considered to be the key sustainability and value objectives before considering the assessment of alternative options or courses of action. Techniques from other disciplines that are not traditionally strongly associated with design and engineering are also reviewed for their appropriateness.

Original research is conducted through developing and employing stakeholder engagement techniques through case studies on real world projects in the built environment, to elicit what represents value and sustainability for a particular context. The approaches are explained, the results are outlined, and feedback from participants discussed. Additionally, reasons why such approaches are valid are justified through reference to how they address gaps in current approaches outlined by the literature.

This section aims to establish the broad values of stakeholders and establish the project sustainability and value objectives on which project decisions can be based. This will include objectives to inform the selection of building elements and systems such as roofs.

1.7 Part 2: The development of an approach and decision support tool (DST) for sustainable roof selection

The overarching research objective of this part of the thesis is, ***"to develop an approach and decision support tool to inform sustainable roof selection."***

This section aims to complement the normative approach to defining decision objectives in Part 1 by providing the facts relating to decision objectives for a roof system. This section focuses on understanding the performance of roofs in areas typically considered to represent sustainability on projects and synthesise this information with sustainability and value objectives to inform decision making.

The literature is first reviewed to understand the areas in which roof systems can typically influence building sustainability and methods for assessing their performances in these areas. Additionally, how roofs address the criteria in common building environmental assessment methods such as BREEAM, LEED and Estidama are also reviewed along with other approaches that have attempted to define what a sustainable roof is and also inform decision making in these areas.

Original work is then undertaken through an action research case study project which aims to assess the challenges of undertaking decision making with respect to performance of sustainable roofs from environmental and social perspectives in the project context, for a Middle Eastern masterplan. How this relates to the challenges of the design process is then reflected on and some of the further issues that need to be addressed outlined. This provides a basis on which the approach to sustainable roof selection and accompanying decision support tool is further developed.

Developments include a method for classifying research on green roof systems according to roof type and climate type in which the research was undertaken, allowing a rapid way for design consultants to find appropriate information. Additionally, a method is defined as a way to rapidly utilising the latest modelling techniques in the project context. This provides a way of providing information on the performance of roof options at the early project stages when information to inform decisions is usually lacking, but the opportunity to influence sustainability is usually the highest. This section provides a way of bringing together information (the facts) on the performance of roof systems with a set of objectives for sustainable roof selection and provides methods of presenting the information transparently to inform decision making.

The approach to decision support also considers how sustainability themes, defined through the softer approaches used in Part 1 of the research, engage stakeholders in the definition of what represents sustainability and value in the context of the project. This provides the information that feeds into the overall approach to sustainable roof selection and informs the objectives of the multi-criteria analysis that helps rank and test the sensitivity of various roof options. The whole approach is based on the value focused thinking methodology, but also considers problem structuring methods to engage stakeholders, broader research and modelling techniques to define the performance of options and the simple multi-attribute rating technique (SMART) as a way of bringing this information together through a robust weighting technique.

1.8 Overall conclusions and further work

This section outlines the overall conclusions and summarises the work undertaken in this research. The work is discussed against the original research objectives and how it has addressed these. The research is evaluated through considering reliability, validity and generalizability. Contributions to knowledge are discussed and the research approach is reflected upon. Limitations are then discussed and further work identified.

1.9 Impact

1.9.1 Publications

- Hampshire, Way, Goodwin (2012), Decision Making with No Data: The challenges of technology selection in the building industry, International Water Association World Congress on Water Climate and Energy, Dublin, May 2012 (Appendix A).
- Hampshire, Goodwin, Tryfonas, Way (2012) Improve the understanding of what represents project value to inform project decision making, 3rd Annual EngD in Systems Research Conference, Bath, May 2012 [1] (Appendix B).
- Hampshire & Melville (2012) Building Values into Valuable Buildings (January 2012) Buro Happold Web Article (http://www.burohappold.com/knowledge-and-news/article/building-values-into-valuable-buildings-701/)
- Hampshire & Melville (2012) Delivering Best Value Through the Value Improvement Process (January 2012) Buro Happold Web Article (http://www.burohappold.com/knowledge-and-news/article/delivering-best-value-through-the-value-improvement-process-702/)
- Hampshire (2011) Not Everyone Loves Chocolate Cake, Patterns (Winter 2011) p33 (Appendix C).
- Hampshire, Goodwin, Tryfonas, Cooke (2011), Mapping the Performance of Green Roofs in Different Climatic Regions: The Development of a Roof Decision Support System for Use in Industry, First Green Roof Student Conference, Sheffield, May 2011 (Appendix D).
- Hampshire, Leak, Francis, Tryfonas, (2010) “An Examination of the Thermal Performance of Green Roofs in the UK” World Green Roof Congress, London, Sept. 2010. CIRIA[2].
- Hampshire, Crawford, Ludwig, Scott, Sydney, Way, (2010) “Integrated Habitats Design Competition Shortlisted Entry - Happy Habitats”, Sustain Magazine.

[1] Won Best Conference Paper
[2] Summary also published in Sustain Magazine

- Sauven, Hampshire, (2010) “Project Reform Embodied Energy Case Study”. Inventory of Carbon and Energy, 2010.

1.9.2 Invited presentations

- Hampshire (2011), Valuing Systems Engineering, Annual Systems Engineering Conference (ASEC 2011), 9th November 2011, Warwick
- Hampshire (2009), “The delivery of sustainable roof systems” International Council on Systems Engineering (INCOSE) Bristol Chapter, May 2009.

1.9.3 Posters

- Hampshire, Goodwin, Tryfonas, Way (2012) Selecting Sustainable Roof Systems, 3rd Annual EngD in Systems Research Conference, Bath, May 2012.
- Hampshire, Goodwin, Tryfonas, Way (2011) Selecting Sustainable Roof, 2rd Annual EngD in Systems Research Conference, Bristol, May 2011.[3]
- Hampshire (2009) Selecting Sustainable Roof Systems, Industrial Doctorate in Systems Workshop, Bristol, May 2011.

1.9.4 Achievements

- Nominated by The University of Bristol for Fellowship with the Royal Commission for the Exhibition of 1851.
- Awarded a Nuffield Bursary Research Grant to support an undergraduate researcher (Value £2,000). Supported undergraduate researcher looking at modelling the thermal performance of green roofs, summer 2011.
- Integrated Habitats Design Competition Finalist (Team leader), June 2010.

1.9.5 Industrial impact

The research has had significant industrial impact. The sponsoring organisation now offers services and has on-going work in the areas that this research addresses. The action research approach has been used to develop approaches which have been used and tested on numerous real world projects. Many of the approaches developed have also been included in several bid applications by the sponsoring organisation and there is now a capability statement based on this research. The work has also been extensively presented and discussed both internally within the sponsoring organisation, including presentations at all levels from graduate forums to executive boards including the sponsoring organisation’s most senior partners and CEO.

[3] Won Best Conference Poster

The work has also been presented externally to numerous clients, architects and students through several lectures at the University of Bristol as well as students at the Schumacher Institute.

1.10 Conclusion

This section has provided an introduction the thesis, including background to the research problem and an overview of its structure and parts. It defines the contributions to knowledge and also the impact of the work. The next section reviews the literature with respect to sustainability for building projects with the intention of considering where the current research gaps are within the industry.

2 Literature review: sustainability for building projects

2.1 Introduction

This literature review aims to give context to the research and the difficulties of defining, measuring, assessing and delivering sustainable development. Many journal papers have comprehensively reviewed the roots of the concepts of sustainability and sustainable development (Kates et al., 2005, Robinson, 2004, Osorio et al., 2005, Sneddon et al., 2006, Lélé, 1991). An overview of the more prominent concepts is given to provide context. The section starts off with the philosophies behind the concepts of sustainability and sustainable development. High level definitions are discussed along with their associated benefits and problems. Different viewpoints and philosophies on how sustainability should be delivered are then outlined.

A review of techniques used to assess the sustainability of buildings is then considered and their strengths and weaknesses summarised. Their changing roles are discussed and future developments outlined. Parallels are then drawn between the concept of sustainability and other complex, value-laden concepts, such as value. The literature review ends with a summary of the gaps in the literature, which guided the development of research questions as detailed in Section 5.2.

2.2 Sustainability / sustainable development

2.2.1 History, concepts and definitions

Whilst sustainability and sustainable development have a multitude of definitions, the terms are often used interchangeably. However some state that there are preferences in the terminology depending on the context in which discussions are taking place and the philosophical stance of the individuals using the language. To give clarity on the philosophy of the definitions, a history of the terms sustainability and sustainable development is summarised briefly.

Sustainability has its roots in the environmental movement that thrust into the public domain the work of Meadows et al. (1972) in their well-known publication, “limits to growth”. The main findings were that:

> *"If no change is made in the trends of world population growth, industrialization, pollution, food production and resource exploitation, our planet's limits of growth will be reached sometime within the next one hundred years. The most probable outcome will be a sudden and incontrollable decline both in population and in industrial capacity… It is possible to alter these growth trends and to establish valid, sustainable conditions for economic and ecological stability. The state of global balance can be designed in such a way as to provide for all basic material needs of human beings on Earth."*

Sustainability places the environmental limits as the most important consideration. Over time this has been expanded to include all natural systems and finally to encompass economic and social criteria as well. In doing so a new concept of 'integral sustainability' has emerged. Today, the term sustainability is generally taken to mean 'integral sustainability' and is understood to incorporate more than just environmental sustainability from which it was derived. However, at its heart, sustaining the environment is the first priority and therefore the term is argued to have a biocentric focus (Osorio et al., 2005).

Sustainable development is a term that emerged from the explicit linkage made between environmental and development issues (Robinson, 2008). The term can be traced back to the 1983 UN General Assembly created the World Commission on Environment and Development (WCED) (Osorio et al., 2005). It was brought into popular consciousness in the report, *"Our Common Future"* (Brundtland, 1987), which is described by some as a critical temporal marker that initiated an explosion of work on development and sustainability (Sneddon et al., 2006). In this report Sustainable Development was defined as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs,"* (Brundtland, 1987). Brundtland (1987) argued that:

> *"The environment does not exist as a sphere separate from human actions, ambitions and needs, and attempts to defend it in isolations from human concerns have given the very word 'environment' a connotation of naivety in some political circles. The word 'development' has also been narrowed by some into a very limited focus, along the lines of "what poor nations should do to become richer," and thus again is automatically dismissed by many in the international arena as being a concern of specialists, of those involved in questions of "development assistance." But the 'environment' is where we live; and 'development' is what we all do in attempting to improve our lot within that abode. The two are inseparable"*

At the time this was trying to reconcile differences between the environmental movement, with the need for development to meet the needs and improve the living standards in poor nations. For the first time, environment and equity became explicit factors in the development equation (Wackernagel and Rees, 1996). The human-centred nature of the Brundtland report, led to the suggestion that the solution to both over and under-consumption lay in promoting more, not less, human development, albeit development that was sensitive to environmental concerns and called for a '5-10 fold' increase in gross world industrial activity over the next century to meet the needs of the poor (Robinson, 2004).

The terms therefore emerged from different backgrounds; the science and the environmental movement for sustainability; and a political background for sustainable development. Different philosophies have therefore developed. For example Sustainable Development has a focus on ameliorating, but not challenging continued economic growth, whereas sustainability focuses attention on the ability of humans to continue to live within environmental constraints (Robinson, 2004). However, others argue that *sustainable development is also based on the preservation of natural resources, that is to say, on the same objectives as sustainability, and is complemented with the search for a social, cultural and economic equilibrium"* (Osorio et al., 2005).

Other differences that are also mentioned across the literature are that *"sustainability refers to the capacity of keeping a state, sustainable development implies a process, which is integrative in essence, and that tries to maintain a state of dynamic balance in the long run,"* (Osorio et al., 2005). Sustainable development as more of a process orientated concept is supported by Parkin (2000) who describes sustainability as the goal and sustainable development as the process towards that goal.

The terms are typically used interchangeably, with a lack of understanding of the philosophical basis from which they were originally derived. Governments and private sector organisations have tended to adopt the term sustainable development, whereas academic and Non-Governmental Organisation (NGO) sources have been more prone to use the term sustainability in similar contexts. However, most of the discourse (which significantly overlaps) has been conducted using the term sustainable development.

Despite decades of work looking at both the terms of sustainability and sustainable development, no single conceptual definition has been reached and there is serious controversy across the literature (Osorio et al., 2005, Ratner, 2004). In fact, Robinson (2004) states that one of the most striking characteristics of the term sustainable development is that it means so many different things to so many different people and organisations. This can be attributed to the generality of definitions such as Brundtland's (1987) which has also spawned many similar high level definitions such as the UK Governments (2008) definition, *"enabling all people throughout the world to satisfy their basic needs and enjoy a better quality of life, without compromising the quality of life of future generations"*. Wackernagel and Rees (1996) state that the term sustainable development is *"treacherously ambiguous"*. They say that many identify more with the *"sustainable"* part and hear a call for ecological and social transformation, a world of environmental stability and social justice, while others identify with *"development"* and interpret it to mean more sensitive growth.

However, the generality of definitions such as the Brundtland definition has stimulated massive response from diverse academic fields, many of which have tried to limit the conceptual reach of sustainable development according to their own area of knowledge (Osorio et al., 2005). In fact some authors state that almost every article, book or paper written on sustainability tends to critique the fact that the concept is broad and lacks agreement. This is often followed by the authors' own definition, which then tends to only add to the lack of consensus (Bell and Morse, 2010).

The Royal Academy of Engineering (2005) attributes the plethora of definitions to the fact that sustainable development and sustainability are very rich concepts. *"It is perhaps safe to say that there is no consensus on the proper definitions, boundaries, or dimensions of sustainability, and no dominant approach to sustainability teaching or research"* (Robinson, 2008).

The question arises as to whether this is a problem? Some authors strongly argue that the high level definitions of sustainable development and sustainability are highly problematic. Some authors explain that the confusion about its meaning and why it matters, has slowed progress towards achieving it (Wackernagel and Rees, 1996). Critique is commonplace that the definitions are ambiguous and malleable. Some argue that the vagueness *“attracts hypocrites and fosters delusions,”* Robinson (2004). O’Riordan (1988) c.f. Ratner (2004) argues that developers, *“seek to exploit the very ambiguities that give sustainability its staying power.”* Mebratu (1998) also references several authors who describe the term sustainable development as *“‘elusive’, ‘an oxymoron’, and ‘devalued to the point at where, to some, it is now just a cliché.”*

However, Varey (2004) points out that the ambiguity of the definitions is not necessarily a bad thing, or in fact uncommon. He states that for all values based concepts, definitions should act more of a virtuous guide, giving direction on where to look, but not being so presumptuous as to be prescriptive in what we will find. He supports this by exploring the Oxford dictionary definition of, “***good*** adj. ~ having the right or desired qualities” and “***beauty*** n. ~ a combination of shape, colour, sound etc. that pleases the senses”. In the case of ‘good’ the qualities required will vary depending upon the context and values of the individual and in the case of ‘beauty’ different combinations of shape, colour, sound etc. will be more pleasing to some than others.

This is supported by Bell and Morse (2010) who state that, “*the flexibility in the term sustainability, whilst potentially reinforcing its popularity can be a great strength in a very diverse world. People differ in the environmental, social and economic conditions within which they have to live, and having a single definition that one attempts to apply across this diversity could be both impractical and dangerous.”*

Undoubtedly definitions such as Brundtland (1987) lead to nontrivial questions that inevitably lead to prolonged debate (Brandon, 1999). What are “basic needs”? What represents a “better quality of life”? What timescale should be considered when talking about “future generations”? Again, the answers to these are likely to be values based and context dependent, but this can be a powerful starting point for dialogue.

Despite all of this ambiguity, no institution has questioned the necessity of reaching the ideal of sustainable development (Osorio et al., 2005). As Ratner (2004) states, *“who could argue for ‘unsustainable’ development?”* According to Mebratu (1998), it is something to which everyone can agree. Additionally, the concept has grown in use and typically has broad appeal. Some authors attribute this success to the very fact that it resists a single, accepted interpretation (Dietz and Neumayer, 2007, Mebratu, 1998). It’s popularity and vagueness provide common ground for discussion among a range of developmental and environmental actors who are frequently at odds (Sneddon et al., 2006, Robinson, 2004, Kates et al., 2005). Therefore the ambiguity provides a starting point for group dialogue around the concept. In fact Kates et al. (2005) explain that the years following the Brundtland report, the creative ambiguity of the standard definition, while allowing a range of disparate groups to assemble under the sustainable development tent, also created a veritable industry of deciphering and advocating what sustainable development really means.

Additionally there are different stances on sustainability, such as *“strong”* sustainability and *“weak”* sustainability (O'Riordan and Jordan, 1995-2002, Turner, 1993, Turner, 2006). Before discussing the positions of strong and weak sustainability it is necessary to introduce the “capital theory” approach. This brings together notions of man-made capital, human capital, natural capital, and social capital (Turner, 2006). Turner (2006) credits Pearce as the person who introduced this perspective and the idea of natural capital, explaining that Pearce saw natural capital as a useful way of integrating ecological sensitivities into economic thinking. We shall use the definition of capital provided by Costanza and Daly (1992) as “a stock that yields a flow of valuable goods or services into the future”. Costanza and Daly (1992) provide the example that a stock of population of trees or fish (natural capital) provides a flow or annual yield of new trees or fish (natural income). If natural capital and subsequently natural income declines then this is not classed as sustainable.

"Weak" sustainability argues that different forms of capital are perfectly substitutable, i.e. natural capital can be substituted with other types of capital. i.e. manufactured or social capital (Gasparatos et al., 2008, Gasparatos et al., 2009). Therefore natural capital can reduce if other forms of capital increases at the same rate. Weak sustainability is based on the assumption of neo-classical economics that manmade capital is a near perfect substitute for natural resources (Daly, 1990, Victor, 1991). Costanza and Daly (1992) give an explanation why different forms of capital are not substitutable. Therefore, a weak sustainability stance tends to represent sustainability from the background of sustainable development (ameliorating but not challenging economic growth). This is typically represented by the Venn diagram model which shows environmental, economic and social systems as interdependent (see Figure 2—1). The zone where the different systems interact is the solution area of integration where sustainability is achieved (Mebratu, 1998). Weak sustainability is more aligned to economics and is closely associated with approaches such as Cost Benefit Analysis (CBA) (Gasparatos et al., 2008).

'Strong' sustainability emphasises that natural capital cannot be substituted for other forms of capital and thus assumes that natural limits should constrain our actions (Daly, 1990). This is generally represented as concentric circles where economic systems, are nested within social systems, which in turn are nested within natural systems (see Figure 2—1). It therefore implies that the economy and society are constrained by natural limits. However, strong sustainability is vulnerable to the critique that it impairs the efficiency of resource allocation to the detriment of present and future society (Howarth, 1996). Howarth (1996) gives the example that a strict interpretation would require an outright ban on the use of non-renewable resources such as oil, even in cases where its use was essential to short term welfare. Approaches that have more of a *strong* sustainability emphasis are those such as biophysical models which look at emergy, exergy analysis and ecological footprint (Gasparatos et al., 2008). This is the stance taken in Ecological Economics. That is that we must learn to live on the annual production from our natural capital, the so called 'interest' generated by our stocks of natural capital (Rees, 1992).

The terms have been dissected further by some authors. For example Turner (1993) c.f. O'Riordan and Jordan (1995-2002) identified four interpretations of sustainability that include:

- very weak sustainability: assumes infinite scope for substitution between natural resources, and artificial substitutes

- weak sustainability: accepts that some life support systems, habitats and human artefacts are important for survival and should be preserved. Such assets are referred to as critical natural assets.
- strong sustainability: provides greater emphasis on critical natural resource protection and enhancement, greater use of assimilative capacity and environmental carrying capacity modelling for policy, pricing and planning and widespread adoption of the ‘critical load’ approach to determining tolerable levels of pollution.
- very strong sustainability, takes this view further to a deep ecology or Gaian view-point through which the intrinsic value of natural objects is given prominence.

Despite the above interpretations of sustainability collated by Turner (1993), in a later paper Turner (2006) states that two basic positions exist and these are simply strong and weak sustainability and these are generally the terms used across the literature today.

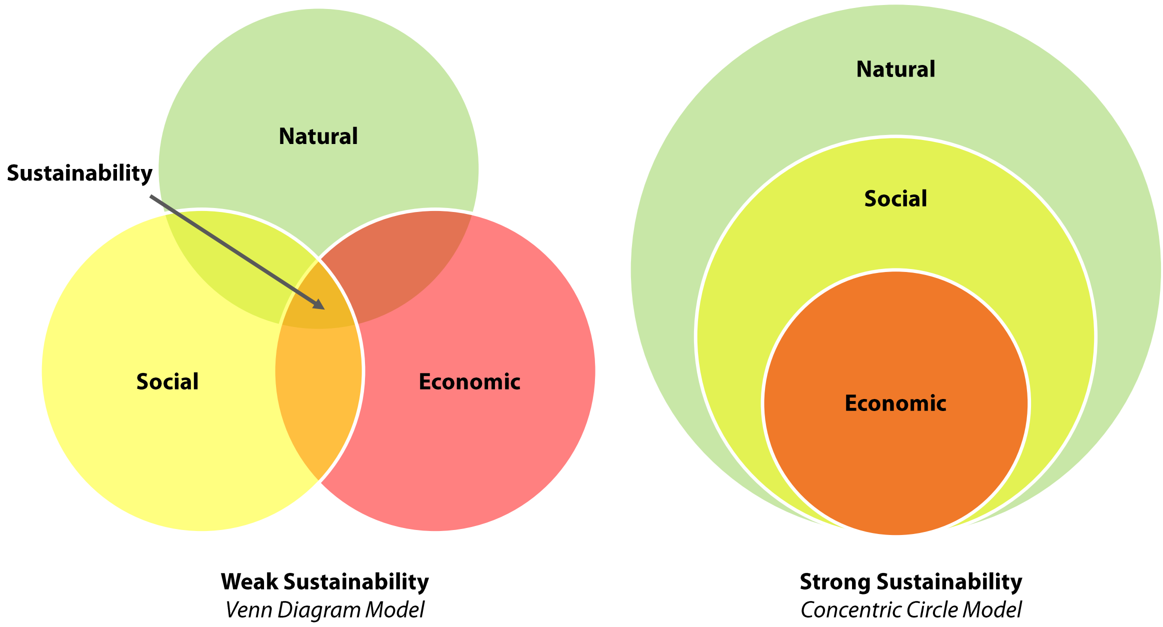


Figure 2—1 Two general models to represent two high level concepts of sustainability

The ecological economics model has been reinterpreted by Forum for the Future, to break the traditional “triple bottom line” approach of balancing economic, environmental, and social systems and instead conceptualise these as resources available for human progress as different sorts of capital. This is known as the five capitals as shown in Table 2—1. The model also implies the strong sustainability approach, stating that, “Natural Capital (the Earth) is the principal source of wealth from which all others flow” (Parkin, 2000) . Parkin’s (2000) model of sustainability argues that environmental and social problems can be attributed to the uneven investment in different types of capital stock. For example by neglecting to ‘invest’ or protect the stocks of natural capital, stocks will become so diminished that the flow of benefits will reduce and human and social capital will also reduce.

Table 2—1 Capitalised stock and flow benefits: a modernised economic model for sustainable development. After Parkin (2000)

Venn diagram/ triple bottom line	Type of capital	Stock	Flow of benefits
Environment	Natural	Soil, sea, air, ecological systems	Energy, food, water, climate, waste disposal
Society	Human	Health, knowledge, motivation, spiritual ease	Energy, work, creativity, innovation, love, happiness
	Social	Governance systems, families, communities, organisations	Security, shared goods (e.g. culture, education), inclusion
Economy	Manufactured	Existing tools, infrastructure, buildings	Living/work/leisure places, access, material resources
	Financial	Money, stocks, bonds	Means of valuing, owning, exchanging other four capitals

It is perhaps not surprising that different conceptions of the meaning of sustainable development and sustainability tend rather to reflect the political and philosophical position of those proposing the definition more than any unambiguous scientific view (Mebratu, 1998, Robinson, 2004). Additionally the concepts have changed significantly over time, with much of the early sustainable development literature focused on economic development, with productive sectors providing employment, desired consumption, and wealth. More recently, attention has shifted to human development, including an emphasis on values and goals, such as increased life expectancy, education, equity and opportunity (Kates et al., 2005). Whilst the early sustainability literatures focused more on environmental limits, sustainability too has integrated social and economic considerations, albeit with different assumptions.

Regardless of the different assumptions on which the terms, sustainability and sustainable development are based, by their definition, sustainability and sustainable development are about looking to the future. There is a wide acceptance that sustainability should be concerned with intergenerational equity. That is that their paradigms imply that whatever is done now does not harm future generations, often termed 'don't cheat on your kids.' (Bell and Morse, 2010, Parkin, 2000). This therefore acknowledges the time dimension of sustainability. Another dimension that both terms need to consider is the spatial dimension. Bell and Morse (2010) therefore believe that two questions need to be answered before exploring the concept of sustainability or sustainable development:

1. Over what space is sustainability to be achieved
2. Over what time is sustainability to be achieved

From this point forward the terms will be used interchangeably. However, within the context of this research, the intention is not to address sustainability from a strong ecological perspective, as considering a roof's performance in relation to ecological limits, which science has not yet been able to define is outside the scope of this research. Therefore this research will seek to develop approaches that improve sustainability of the roof from a 'weak' sustainability perspective, reflecting that of the original philosophy of sustainable development. It will consider how we can make decisions regarding the choice of roof system that offer improved social, economic and environmental value for the stakeholders of the project. However first we seek to understand the different approaches to delivering sustainability.

2.2.2 Approaches to practice

> *"...if defining it [sustainable development] is difficult, putting it into practice is even harder,"* (Parkin, 2000).

Definitions of sustainability can be clasified into 'positivist' and 'normative' terms (Meppem and Gill, 1998, Osorio et al., 2005). This looks at two different approaches to the delivery of sustainability and sustainable development. Keynes declared that a *''positivist science may be defined as a body of systematised knowledge concerning what is; a normative or regulative science as a body of systemised knowledge relating to criteria of what ought to be''* (Keynes, 1890, p. 34 c.f. Meppem and Gill 1998).

In relation to sustainability, Osorio et al. (2005) explain that the positivist approach aims to define environmental limits and what is allowable through scientific analysis. This approach looks at sustainability from the perspective of ‘what it actually is’. The normative approach refers to more institutionalised sustainability. It involves agreements and refers to ‘what should be’ as defined by groups of actors. These represent the two extremes. More recently there has been the development of approaches which try and merge the two approaches and come to a common middle ground. This is referred to by this author as pragmatic realist sustainability. These approaches to practice are now covered under the following headings.

2.2.2.1 Positivistic sustainability

Science within the context of sustainability emerged in the early seventies with the publication of the Limits to Growth as outlined in Section 2.2.1. Since then science has been placed at the service of sustainable development and efforts have developed technological tools and new theoretical knowledge through which environmental impacts and their possible economic and social consequences could be known (Osorio et al., 2005).

With respect to positivist sustainability we are referring to the stance that science is based upon the scientific method and its application will be able to objectively tell us what is or is not sustainable. The scientific method involves observing the world in a systematic way, seeing problems, collecting data and testing theories about why the problems are there and rejecting hypotheses that are perceived to be ‘wrong’. In this approach, issues such as whose problems, whose perceptions of problems, whose justification for action, whose idea about what data is legitimate, who are legitimate stakeholders in the problem context, and what are their views are not relevant questions. Essentially positivistic sustainability is concerned with reductionism. Webster (1995) (cited from Bell and Morse (2010, p107)) defines this as *“the attempt to explain all biological processes by the same explanations (as by physical laws) that chemists and physicist use to interpret inanimate matter; also: the theory that complete reductionism is possible; (2) a procedure or theory that reduces complex data or phenomena to simple terms”* Therefore reductionism reduces wholeness to individual parts to make them understandable. The scientific approach to understanding is to stand back, take an objective worldview and seek the truth (Bell and Morse, 2010).

The extreme of the scientific approach is typified by the laboratory experiment, where things are tested in a controlled environment and variables isolated. The process and results of such experiments are considered repeatable. However, such approaches have also been applied on global scales to try and understand the global climate system. This takes a scientific approach and uses this to build models of the system to forecast its future behaviour. These models however are a gross simplification of the actual system, which is necessary as computing power is limited and so is the data on the actual performance of the whole. Additionally, when applied on a large scale outside the laboratory, the external conditions cannot be controlled. Furthermore the researcher is not able to stand back and merely observe as they themselves are part of the system. External factors come in to play. For example their behaviour can influence the system they are studying and their next set of funding may depend upon their results. Thus the ability of the research to remove themselves from the process is difficult.

Many scientists tend to assume that sustainability is a ‘truth’, ‘end-state’ or a ‘fixed target’ (Bagheri and Hjorth, 2007). Essentially from a scientific point of view, sustainability is concerned with the ‘actual capacity of a system to maintain its productivity against disturbances.’ Essentially it is concerned with ‘what it actually is’ rather than ‘normative’ sustainability which refers to ‘what it should be’ (Osorio et al., 2005) (see Section 2.2.2.2). Whilst classical science has provided good evidence of environmental degradation and brought environmental issues to the forefront of political debate, there is still a lack of consensus on what the replenishment and assimilative capacity of natural systems is (Meppem and Gill, 1998). Therefore a precise definition and measurement of “critical” natural capital, is still an open scientific question (Turner, 2006) and as such no agreement on ‘what must be sustained’ has been reached (Osorio et al., 2005). Therefore criteria cannot be derived and unambiguous decisions on how to get there cannot be made (Bagheri and Hjorth, 2007).

Someone arguing from a positivist sustainability perspective would argue that science should provide us with a *“technical means for making commensurable the values indicated in the distinct dimensions of sustainable development”* (Ratner, 2004). However a comprehensive accounting framework based upon technical understanding that integrates economic, environmental and social dimensions of development remains elusive (Ratner, 2004). Essentially from a positivist perspective sustainability should pose an indisputable argument, because whatever sustainability is it must be conjugated with balance in use and spending of natural resources (Osorio et al., 2005).

However, the approach has received much attention recently and also much criticism. Some of these criticisms are as follows. Often the advocates of universalising types of aggregate measures fail to acknowledge how arriving at a common metric can be far from technical. Whilst some processes can be informed by scientific technique, ultimately judgements are required based on moral principles and beliefs (Ratner, 2004). Despite this, the outputs of such techniques are often held up as quantifiable information and evidence of a value free process for objective analysis (Meppem and Gill, 1998). Such techniques have been described as *"…at best a useful approximation, and at worst implying a false veneer of confidence that is part of the problem itself"* (Meppem and Gill, 1998).

Whilst scientific research has given us a much better understanding of our impacts, it has failed to provide solutions to the complex problems that we face as a society, such as climate change, food shortages in the developing world etc. This has led to the decline in the legitimacy of authoritative science and the rise of more discursive, democratic science, which includes ecological economics, political ecology and the new thinking generally in the social sciences (Sneddon et al., 2006). Osorio et al. (2005) argue that, "classical science can no longer afford the fact that its explanations do not relate to space, time and process". Reasons given are that the complexity and interdisciplinary nature of the problems we now face cannot be addressed by classical science, which is based upon a reductionist concept of phenomenal reality and studied within increasingly more specialised and esoteric disciplines (Osorio et al., 2005). Funtowicz and Ravetz (1993) agree with Kuhn (1962) in their well referenced article on post-normal science that 'normal' science is characterised by puzzle-solving approaches that exclude uncertainty. Therefore classical science undervalues uncertainty, but this is an intrinsic feature of reality itself (Osorio et al., 2005). Especially in interdependent, interdisciplinary systems where things are complex and not well controlled or repeatable. Additionally, the scientific method usually has good quality assurance as it is laboratory based, variables are isolated and the tests are repeatable. However, even science has been criticised with respect to finding what scientists would explain is the truth. Magee (1994) states in his book on Karl Popper, *"the whole of science assumes the regularity of nature – it assumes that the future will be like the past in all those respect in which natural laws are taken to operate – yet there is no way in which this assumption can be secured. It cannot be established by observation, since we cannot observe future events. And it cannot be established by logical argument, since from the fact that all past futures have resembled past pasts it does not follow that all future futures will resemble future pasts."*

With respect to environmental and political issues this is particularly true, even if scientific models show good predictions using past data, this does not imply that they will be good predictions for future impacts. This is particularly relevant with respect to forecasting climate change and related policy decisions. Additionally, experiments and models based on such a large scale with all the complexities of the real world are time consuming and decisions need to be made now on important issues. This is an extremely important point with respect to politicians and practitioners who need to make decisions now on what they believe to be the best future option within the constraints of the situation. They do not have the luxury of complete information and zero uncertainty.

Some of the criticisms highlighted above have led Funtowicz and Ravetz (1993) to believe that, *“by the traditional criteria of scientific method, the quality of research on these policy-related problems is dubious at best.”* Sustainability or unsustainability, along with all its complexities, is an urgent problem that needs addressing now. As science cannot give us clear targets and ways to progress, some have argued that traditional discipline-led science is unable to cope with the complexities of sustainable development (Osorio et al., 2005, Bagheri and Hjorth, 2007, Funtowicz and Ravetz, 1993). Perhaps this failure of classical science explains why a considerable proportion of the science and technology community became increasingly estranged from the societal and political processes that were shaping the sustainable development agenda (Kates et al., 2001).

Despite this general critique of positivist approaches, there have been some widely referenced and highly regarded attempts to define natural limits. This includes the work of Karl-Henrik Robert and John Holmberg in defining criteria/principles for sustainability often referred to as The Natural Step (TNS) System Conditions (Robèrt et al., 1997, Holmberg, 1998). Such principles have been consequently agreed as valid and useful through extensive rounds of dialogue amongst leading scientists and practitioners in Sweden, and subsequently in many of the countries in which The Natural Step (TNS) network of scientists and business corporations operates. There are four criteria, also referred to as principles or system conditions. The premise is that any sustainable society would meet these principles. Interestingly, they flip the problem of not being able to define sustainability on its head, by instead taking an approach to understanding what we know *not* to be sustainable. Holmberg describes these as, “principles that determine what human activities must not do.” These principles were originally conceived by considering the principle ways that humans could destroy the ecospheres ability to sustain us. These were defined in the early 90s by Robèrt et al. (1997) and refined through multiple workshops and rounds of dialogue.

"Humans can destroy the functions and biodiversity of the ecosphere by (Holmberg and Robèrt, 2000):

a. *A systematic increase in concentration of matter that is net-introduced into the ecosphere from outside.*
b. *A systematic increase in concentration of matter that is produced within the ecosphere.*
c. *A systematic physical deterioration (harvesting and manipulation) of the ecosphere's ability to utilise waste as building blocks for primary production, and to provide other essential functions.*

The systems conditions for sustainability are then formed through adding a negation to the above three terms to give the following:

In a sustainable society, nature is not subject to systematically increasing:

1. *concentrations of substances extracted from the Earth's crust;*
2. *concentrations of substances produced by society;*
3. *degradation by physical means.*

And, in that society:

4. *people are not subject to conditions that systematically undermine their capacity to meet their needs.*

The first three systems conditions provide the framework for ecological (strong) sustainability which provide a set of restrictions through which activities must be constrained. However, as the primary causes of rapid changes in the natural environment is human action, the fourth system condition focuses on the social and economic considerations that drive the above actions.

However, whilst they concede that it is very difficult to foresee what concentrations of matter will lead to unacceptable consequences, Holmberg and Robèrt (2000) explain that a general rule is not to allow deviations from the natural state that are large in comparison to natural fluctuation, and in particular, deviations should not be allowed to systematically increase.

Interestingly whilst many authors state that sustainability is hard to define (see Section 2.2.1) with typically significant disagreement on definitions, (Holmberg and Robèrt, 2000) states that with respect to the principles for sustainability defined above, “the area of agreement is often larger than expected… [and] often the dispute turns out to be about the different means to handle certain requirements for sustainability (actions) rather than about the requirements themselves.”

Rockstrom et al. (2009b) provided a start to the quantification of a set of “planetary boundaries” in their highly regarded work published in Nature. This explains that the planet’s environment has been relatively stable for a period of approximately 10,000 years, a period known as the Holecene. During this period, the environmental change occurred naturally, and earth was able to regulate conditions which enabled humans to thrive. However, a new age, termed the Anthropocene, has emerged since the industrial revolution. This defines an era where human actions have now become the major driving forces behind global environmental change. This has emerged largely due to a rapidly growing resilience on fossil fuels and industrial forms of agriculture. They have therefore defined a set of boundaries which represent a safe operating space for humanity. If these boundaries are crossed, then important subsystems could shift into a new state, with potentially disastrous consequences for humans. They explain that in general, planetary boundaries are values for control variables for processes with evidence of threshold behaviour, or at dangerous levels, for processes without evidence of thresholds.

However, they note that determining a safe distance requires normative judgements of how societies chose to deal with risk and uncertainty and where they have made quantitative definitions they state that they have taken a “conservative, risk-averse approach”. A detailed description of the various boundaries and their quantification is given in (Rockstrom et al., 2009a). In summary, the work details that three of the nine/ten planetary boundaries (Biogeochemical flow boundary can be split into 2 sub boundaries for nitrogen and phosphorus) are currently being exceeded. These include; climate change (measured in atmospheric carbon dioxide concentration measured in parts per million by volume); rate of biodiversity loss (measured in extinction rate (number of species per million species per year)); and nitrogen cycle, part of the boundary with the phosphorus cycle (measured in amount of N2 removed from the atmosphere for human use (millions of tonnes per year)). Their work also explains that the planetary boundaries are tightly coupled meaning that if one boundary is transgressed, then other boundaries are at serious risk.

Whilst the above work represents a move towards quantifying some of the planetary boundaries, it does not provide a means of change (through actions) or a way of addressing the impact on social and economic systems.

In summary, positivist sustainability is about utilising scientific approaches to define a blueprint for sustainability. However, whilst positivist approaches have improved our knowledge about environmental limits in some areas, these approaches have not yet been able to define them comprehensively and understand the relationships between various limits. Additionally it cannot provide a means of changing our complex economic and social systems to work within those limits (even if they are defined). Other approaches are also required. Additionally, science is best practiced under controlled circumstances, such of those of laboratories, and its strength comes in its repeatability of its results. This is not possible on a global scale, where time frames are large, and impacts potentially global. No control is therefore possible.

However with respect to sustainable energy, Mackay (2008) states that if we are going to solve the problems of energy it is ‘numbers, not adjectives’ that should inform the debate. However, this is the difference between a pragmatic realist position and a truly positivist one. Mackay is effectively saying that they should inform the debate. Therefore numbers should be used within normative approaches.

2.2.2.2 Normative sustainability

In contrast to *“positivist”* sustainability, *“normative”* sustainability refers to *“what it should be”* (Osorio et al., 2005). It involves dialogue and discussion and is a process based approach. Some authors argue that sustainable development should be addressed as a process rather than a fixed goal and this is considered to have a key role in sustainable development in terms of definition, practice and planning (Bagheri and Hjorth, 2007).

Normative approaches take the stance that generalisable laws cannot be used in situations where context is so important. These normative approaches are referred to by Osorio et al. (2005) as ‘institutional’. It involves the agreements and proposals generated within the conceptual frame of sustainable development.

Brandon (1999) explains that a normative approach is required, as the features of sustainability *“will be seen to be embracing of some of the most complex issues known to man and it would be unwise to move down the path of setting specific goals with high expectations. It is likely to be an exploration, a journey, a revealing, rather than a conclusion which we can expect as we progress”.* Other authors argue for a normative approach because*, “democratization is a work in constant progress, and that thoughtful exchanges among different members of a society – on broadly equal terms – about the social goals of that society are indeed the essence of any conception of democracy. But as has been emphasized in the literature of ecological economics, it is not just a matter of sharing and adjusting goals. We each see different aspects of social and environmental reality from different positions in society and through different lenses of expertise (Norgaaard 1994, 2004; O’Hara, 1996)”* c.f. Sneddon et al. (2006).

Anderson (1993) c.f. Ratner (2004) argues that all criteria for social action, even quantitative calculation, require defining the consequences of action and determining their desirability in reference to social norms and values. Thus, there is no scientifically objective (i.e. value-free) basis for judging efficient paths of action. In essence, all social action is framed by values, whether consciously acknowledged or not.

Emerging from the literature from the normative stance, is the idea that science is unable to provide the means of achieving sustainable development and isn’t even able to set appropriate goals, as what is considered more important will always be that of political debate. Therefore this needs to be acknowledged and considered through debate and dialogue. This can often been seen in the context of building projects where there is uncertainty in what the “Client” or a group of stakeholders even want to achieve, which is an important first step in trying to understand what to design.

Approaches that sit at the extremes of either positivist or normative sustainability are rare and becoming less fashionable. Meppem and Gill (1998) conclude that the evidence from various quarters of science, sociology, philosophy, economics and law suggest that the conventional normative/positivist focus of the sustainable development debate is an outmoded epistemology. Consequently, there is an increasing amount of literature based on developing or mixing positivist and normative approaches. This author has termed this ‘pragmatic realist’ sustainability. This is discussed in the following section.

2.2.2.3 Pragmatic realist sustainability

"Pragmatic realist sustainability", a term defined by this author, refers to utilising a mixture of approaches and lies between the two extremes of normative and positivist approaches to sustainability. Some argue that the distinction between the normative and the objective (positivist), the 'ought' and the 'is' is not useful when the system under scrutiny entrains human values and choices as irreducible and critically important system constituents and drivers of change (Swart et al., 2004). A growing body of literature is acknowledging the weaknesses of approaches which have a strong bias towards either normative or positivist sustainability, and a middle ground is emerging (Meppem and Gill, 1998, Meppem and Bourke, 1999, Meppem, 2000, Ratner, 2004, Gasparatos et al., 2008, Gasparatos et al., 2009, Kates et al., 2001).

Pragmatic realist sustainability is supported by Brandon (1999) who states that, *"It would be dangerous to promote a single view or perspective of a problem which is so complex. Nevertheless some rationale is required" (Brandon, 1999).*

Ratner (2004) states that, *"No objective means can exist for making tough social choices. Interpreting sustainability as a dialogue of values, in which technical and ethical consensus are desirable but not adequate means of reaching collective decisions in complex disputes, places an emphasis on social actors, their dynamic processes of interaction, and the characteristics of governance that structure those processes."* In arguing this, Ratner essentially is arguing a pragmatic realist stance of sustainability being a dialogue of values whilst accepting that technical (scientific) and ethical consensus are important.

Robinson (2004) also argues that "there is a wide diversity of viewpoints as to what sustainability is and entails and that there is constructive ambiguity in keeping open some of these issues. The other side of that coin is that there is a need to develop processes that make use of that constructiveness, that allow diversity to be expressed without creating paralysis…This is particularly the case where there exists fundamentally different views about questions of value and meaning… these are profoundly moral and political issues, which require thoughtful deliberation and collective resolution…This question can only meaningfully be answered I think as part of an incremental process of collective decision making that is based on, but not determined by, expert knowledge that is open to multiple perspective but not paralyzed by them; that allows for, and reinforces, social learning and changes in views over time; and that is provisional but concrete…". This perspective respects the need of collective input and resolution and technical knowledge, considering both the normative and the positivist in what this author has termed a "pragmatic realist" approach.

Other arguments for a pragmatic realist perspective on sustainability include Sneddon et al. (2006) who argue that embracing pluralism provides a way out of the ideological and epistemological straightjackets that deter more cohesive and politically effective interpretations of sustainable development.

Ratner (2004) argues that, *"when actors agree on the meaning and measurement of a goal, and recognise as legitimate a means of discerning among alternatives in relation to that goal, then they have delimited a realm of decision-making in which technical means-end calculation can reign… likewise, when actors ascribe legitimacy to a set of ultimate values and attempt to align their collective actions in harmony with these, they are engaged in constructing distinct realm of social action."* It follows that , "*Stakeholder involvement is important, as there is increasing public distrust of expert-driven decision making, growing awareness of a diversity of opinions in the scientific community, and increased sophistication of NGO, private sector and public involvement in regulatory and other decision-making… participatory forms of scenario analysis could be particularly effective in addressing the strategic and normative elements of the sustainability questions by incorporating values and preferences into the scenario analysis process itself"* (Swart et al., 2004).

Consequently, new areas of study, such as ‘sustainability science’, are emerging that seek to understand the fundamental character of interactions between nature and society (Kates et al., 2001). Sustainability science aims to account for the interaction of global processes with ecological and social characteristics of particular places and sectors. It will also require fundamental advances in our ability to address such issues as the behaviour of the complex self-organising system as well as the responses, some irreversible, of the nature-society system to multiple and interacting stresses. Combining different ways of knowing and learning will permit different social actors to work in concert, even with much uncertainty and limited information.

These echo many of the ideas outlined by *Funtowicz and Ravetz (1993)* in their definition of post-normal science, which looks to integrate hard (scientific) and soft (social) approaches. Post-normal science is emerging as a strategy to deal with environmental issues in which there are high uncertainties and various and conflicting values, and in which urgent decisions are needed (Osorio et al., 2005). Essentially, post-normal science seeks to integrate systems within the frame of holistic explicative models that will transcend reductionist models of normal science. This adopts a *“systemic, synthetic and humanistic approach”* which recognises complexity and natural systems dynamism and their subsequent problems are paramount.

This emphasis upon problems is also a defining characteristic of ‘post normal science (PNS). PNS, focuses on problems that are introduced through policy issues where facts are uncertain, values are in dispute, stakes high, and decisions urgent (Robinson, 2008). Post-normal science does not oppose classical science and its methodology, but aims to complement it.

PNS deals with problems which are high in terms of decision stakes and systems uncertainties and there are no past examples of management and no accepted methods or technologies. Ravetz (1986) states that in such cases the problem is, “*total in its extent, involving facts, interests, values and even lifestyles”.* However, Rosa (1998) c.f. Turnpenny et al. (2011) argues that in such situations, solutions can be generated by creating structures and institutions where creative dialogue is encouraged and developed. Drawing on the concept of PNS, they state that in such cases, traditional experts should be surrounded with an extended peer community (EPC) or those who will be affected by the experts’ knowledge.

In such cases, the EPC will contribute important knowledge and understanding of local conditions that traditional experts may not have. Thus the EPC becomes a vehicle for the transmission of skills and the quality assurance of the results (Turnpenny et al. 2011) . Essentially, PNS integrates contextually informed insights of stakeholders with those of technical stakeholders in EPCs to generate extended factors. The purpose of this is to help balance the technocratic nature of traditional decision making by engaging with uncertainty. Therefore EPCs help ensure that solutions proposed are contextually informed. However, PNS still then aligns with traditional logic which assumes that superior outcomes rest on the quality of facts informing them (Healy, 2011). The systems nature of PNS therefore transcends the ability of traditional, technically focused decision making to consider facts, values and politics (Healy, 2011).

However, whilst stakeholder involvement emerges as important in pragmatic realist approaches, Kates et al. (2005) warn that through their real-world experience, achieving consensus on sustainability values, goals and actions is extremely challenging. They describe it as difficult and painful work. They also state that, *“sometimes individual stakeholders find the process too difficult or too threatening to their own values and either reject the process entirely to pursue their own narrow goals or critique it ideologically, without engaging in the hard work of negotiation and compromise”.*

Despite this, various pragmatic realist approaches have been developed through engagement with stakeholders on a broad scale. These include various indicator initiatives with the aim of defining what is to be sustained and what is to be developed and for how long. This includes various initiatives such the “Commission on Sustainable Development”, “Wellbeing Index” and “Environmental Sustainability Index” as well as a multitude of others. They all contained different numbers of indicators, with different considerations of what is to be sustained, what is to be developed and over what time frame this should be assessed. Some of which also provide quantitative scientific measures on how the performance of systems can be assessed.

Approaches have also been developed that combine stakeholder engagement along with scientific principles to define sustainability for specific contexts and then utilising a broad range of skills sets and where possible the results of applied science to consider the performance of different options or courses of action on how to progress.

Such approaches include The Natural Step's Backcasting Approach (Holmberg, 1998, Holmberg and Robèrt, 2000) and DesignWays (Tippett, 2005, Tippett et al., 2007). Both of which take a strong sustainability stance, basing their fundamental reasoning on ecological principles. There are also other approaches that take a weaker sustainability perspective, which include decision analysis.

The Natural Step's Backcasting Approach (Holmberg, 1998) is a method for strategic planning that was developed in co-operation with and applied by The Natural Step (TNS) network of scientists and business corporations. Holmberg (1998) explains that the main difference between their approach and that of others are that the method is based on a framework of four non-overlapping principles of sustainability, and the method of backcasting. The backcasting method tries to free participants from today's problems and trends to understand what requirements and possibilities sustainability will involve in the future. This is in contrast to traditional forecasting, which places an emphasis on predicting the future from today's trends. A business justification for using the backcasting approach is provided in Holmberg and Robèrt (2000). The method consists of the following four steps (Holmberg, 1998):

1. **Conditions for sustainable society (often referred to as TNS System Conditions) are defined:** This is the starting point and consists of the criteria for a sustainable future based on TNS sustainability criteria which are based on scientific principles. Such principles have been agreed as valid and useful through extensive rounds of dialogue amongst leading scientists and practitioners in Sweden, and subsequently in many of the countries in which TNS has been licensed (Robèrt, 2000, Tippett et al., 2007). There are four criteria, also referred to as principles or system conditions. The premise is that any sustainable society would meet these principles. Interestingly, instead of trying to define what is sustainable through scientific knowledge they instead flip this and define what we know *not* to be sustainable. Holmberg describes these as, "principles that determine what human activities must not do." These principles were originally conceived in the early 90s by (Robèrt et al., 1997) and refined through multiple workshops and rounds of dialogue (Holmberg and Robèrt, 2000). There are other aspects of the TNS framework which include the funnel metaphor to aid awareness of the overall problem of non-sustainability. This utilises the narrowing walls of a funnel to represent the ecosphere's capacity to support our present day economies, and life itself. Whilst the resource throughput (what goes through the funnel) is increasing. For more information see (Holmberg, 1998, Holmberg and Robèrt, 2000, Robèrt, 2000).

2. **The current situation in relation to the criteria for sustainability is described:** The firms current activities and competences are analysed in relation to the system conditions (criteria for sustainability). This is in order to make scenarios realistic, it is useful to have a good grasp of current competences and activities.
3. **Future possibilities for the firm are envisaged:** In this step, future possibilities are envisaged based on the principles of a future sustainable society (step 1) and the inventory of the current situation (step 2). It is often useful to take a leap forward and discuss the role of the organisation in an assumed sustainable situation. This may be supported by example questions such as: What are my organisations fundamental reasons for existing beyond making money? The main purpose of such questions is to attempt to step away from the present situation and current restrictions. The core values (the organisation’s enduring guiding principles; those things that can never be compromised for financial gain or expediency) and the purpose are essential for success (Collins and Porras, 1996).
4. **Flexible strategies are identified that can link the present situation with the desirable future sustainable situation:** This step involves identifying strategies that can link the present to the future sustainable situation. For each strategy/measure presented it is posited that the following four points should be considered. These are paraphrased as, Will each measure:
    a. bring us closer to sustainability?
    b. be a flexible platform for the next step towards sustainability?
    c. pay off soon enough?
    d. Collectively help society to make changes at a sufficient speed and scale to achieve sustainability without too many losses for humans and other species during the transition?

All these points are relevant to each strategy, for example, if they are not combined, then there may not be enough money or pick seemingly quick win options which do not provide flexibility to take future steps towards sustainability. (Holmberg, 1998) explains that tools such as LCA or quantitative indicators are relevant and useful, they are unable to cover all parts of sustainability. He explains that there are many advantages of guiding the use of quantitative tools by such hierarchical questions. These are listed below (Holmberg, 1998):

1. The framework and the principles make more sense and will be easier to grasp
2. It is easier to identify which aspects should be quantitatively analysed.
3. It is easier to identify which aspects are not quantitatively analysed.
4. It is easier to communicate the results, because of the logical structure

5. Solutions can be found with less effort, since it is easier to avoid unnecessary quantative analysis.
6. It is also possible to cover aspects that are difficult to analyse quantitatively.

The approach is considered particularly useful when (Dreborg, 1996, Holmberg and Robèrt, 2000):

- The problem to be studied is complex
- There is a need for major change
- Dominant trends are part of the problem
- The problem to a great extent is a matter of externalities
- The scope is wide enough and the time horizon long enough to leave considerable room for deliberate choice

Additionally the approach should not be seen as better than or an alternative to LCA, Ecological Footprint and other metrics (Robèrt, 2000). Robert (2000) provides a framework for how tools and concepts for sustainable development relate to the backcasting approach and the TNS System Conditions. This has been called the Framework for Strategic Sustainable Development (FSSD). In this work Robert proposes a 5 layer hierarchical model which describe the relationships between principles, activities, and metrics within a system. These consist of the following:

1. Principles of Ecosphere (Social and Ecological Constitution)
2. System Conditions (Principles of Sustainability)
3. Strategy (Principles for Sustainable Development)
4. Activities
5. Concepts and tools (Metrics)

The TNS Framework covers level 2 (System Conditions) and level 3 (Strategy) (Holmberg and Robèrt, 2000, Robèrt et al., 2002). Whilst tools such as LCA, Ecological Footprint, Factor 4, etc. are focused at Level 5 of the hierarchy. However, that is not to say that they are any less important, but just have different purposes (Holmberg and Robèrt, 2000, Robèrt et al., 2002).

Recently, Robèrt et al. (2013) detailed how the planetary-boundaries and the systems conditions (outlined in Section 2.2.2.1) could be combined in complementary ways through the Framework for Strategic Sustainable Development (FSSD). The combined approach allows for prioritisation of actions based on planetary boundaries, but also allows for action to be taken based on the system conditions when planetary boundaries have not yet been defined. Other complementary aspects are that, the systems conditions also provide guidance that can be used at different levels of scale, from individual to organisational and ultimately global. Whereas the planetary boundaries are applicable at the global level, which to most actors, will appear simply beyond their scale.

Building on the TNS FSSD framework, DesignWays (Tippett, 2004, Tippett, 2005, Tippett et al., 2007) is a methodology for enabling community and stakeholder participation in ecological planning. DesignWays methodology explicitly integrates participatory and ecological planning approaches to bring together appropriate stakeholders to translate sustainability guidelines into practice. The full process consists of the following stages and takes approximately 30 hours, in a series of workshops:

1. Creativity
2. Context
3. Sustainability
4. Limits and Solutions
5. Values and Goals
6. Filtering Ideas
7. Ecological Design
8. Landscape Analysis
9. Integrated Decision Making
10. Design Synthesis
11. Action Planning
12. Implementation and Review

For a fuller description of the above stages see Tippett (2004) and Tippett (2005). Within the DesignWays methodology, the TNS Framework is taught early in the process (Stage 3) and design options are tested against the TNS Framework. Design options are again filtered against the TNS Framework in Stage 6 (Filtering Ideas) of the process and also flagged in Stage 9 (Integrated Decision Making) if they are violating sustainability criteria. The process has been used in the context of waterside regeneration in the Mersey Basin Campaign. Tippett (2007) also undertook a conceptual appraisal of the DesignWays methodology by critiquing it against the challenges of sustainability. This also included a critique of a range of existing participatory and ecological planning methodologies against the challenges of sustainable development and thus emphasised the scope for DesignWays as a new methodology.

However, pragmatic realist approaches in the context of this research are those that combine positivistic and normative aspects. They do not necessarily have to address sustainability from a strong sustainability perspective. Other approaches considered pragmatic realist and action orientated include those that help develop and select between options from a weak sustainability perspective. These essentially involve action orientated approaches, that allow for the substitutability of capital. Such approaches include cost benefit analysis and other techniques which allow substitutability of different forms of capital.

In the context of this research, set in the context of roof decisions on building projects in an industrial context, the design team are typically employed by a client to enable them to achieve what they value for the project in the most effective manner. What they value and wish to be developed (for them) may not align with principles of sustainability as outlined by Robert (2000). Translating the principles into building projects at the scale of building projects itself is difficult. For example, the design team may not have influence over the siting of a project which may degrade the environment by physical means, concentrations of substances extracted from the earth's crust to build the project, etc.

The problem context is then changed and it becomes one of how to develop and select the best option to deliver what they value in the most sustainable means possible under the project constraints. Therefore, other pragmatic realist approaches include decision analysis approaches which can be used to select the option that provides the most sustainable value from an environmental, social and economic perspective, whilst accepting substitutability of capital may be significantly out of the hands of the design team. Additionally, if the most sustainable solution is not considered good value by the person or group of people paying for the project, then it is unlikely to be delivered.

The next sections consider how sustainability is currently considered with respect to the design of the built environment.

2.3 Sustainability in the built-environment

> *"Within this overview of sustainability as a concept the built environment represents a subset. It is however a significant player in its own right and also has a significant impact on the world in general. Looking in, it engages the most basic needs of man in terms of accommodation, comfort and social organisation. Looking out, it impacts on the quality of the natural environment, the quantity of non-renewable resources and the services needed to support human gatherings in any form. At its most prevalent, within the urban context, it permeates the whole fabric of human existence and extends into the ecosystems upon which all living species depend. No consideration of sustainability can avoid consideration of the structures human beings have developed to accommodate themselves"* (Brandon, 1999).

The built environment has a significant impact on sustainability. This is evident in its sheer scale. For example in the UK, construction's output is worth over £100 billion per year and accounts for 8% of national GDP (HM Government, 2008). Globally this is even higher at 11% and this is set to rise to 13% of global GDP by 2020 (Global Construction Perspectives and Oxford Economics, 2011).

In the book, *'Sustainability in the Built Environment'* (Atkinson et al., 2009), the following are listed as the impacts of the built environment:

- Climate Change (global warming, carbon emissions, energy use, global dimming)
- Water Resources (water availability, over-use, flooding, salinisation, water security)
- Pollution (water, marine, air, acid rain, soil)
- Soil Erosion
- Land Take
- Land Remediation
- Biodiversity
- Habitat destruction
- Damage to ecosystems
- Resource depletion
- Ozone depletion
- Desertification

- Population

These reflect only the environmental impacts and do not consider the social and economic implications which are also vast as the built environment is where humans spend the majority of their time. There are many tools to help designers in improving social, economic and environmental impacts. These include at the most basic level regulatory and voluntary standards. A summary for the UK is provided by Atkinson et al. (2009). In this they also review their relevance for different stages of the design process. This includes:

- Planning and Infrastructure
- Design
- Materials & Procurement
- Construction
- Use
- Maintenance and Refurbishment
- Property sale/ transfer
- Demolition

As far back as 1998, there was a growing consensus that appropriate strategies and actions were required to make the built environment and construction activities more sustainable (Barrett et al., 1999). Techniques such as the Delphi method were used to develop consensus, across two panels of twenty national and international experts, of definitions for sustainability with respect to construction (Barrett et al., 1999). There was a strong agreement between definitions for the industry although the international definition was more ecologically centred rather than human centred and was also at a slightly larger spatial scale. The approach outlined in the paper also asked the expert panels to set objectives and prioritise these whilst also identifying the stakeholders that should be involved. The top objectives for the industry as defined by both panels separately were prioritised as shown in Table 2—2.

Table 2—2 Top objectives as defined by national and international panels

Objective (Priority)	Primary Stakeholders
Reduced energy consumption in buildings (First)	Clients, Designers, National Government
Reduce consumption of non-renewable resources (Second)	Clients, Designers, Material Manufacturers
Develop clear national sustainability policy and plans (Third)	National Government

We focus here on approaches to measuring and improving decision making with respect to sustainability for design projects in the built environment. This fits with the context of this research working within an international and interdisciplinary engineering consultancy. Bell and Morse (2010) (p77) describe projects as human constructs that revolve immediately around human wants and desires. Additionally they explain that they have well defined boundaries and involve people in a defined space and therefore sustainability concerns move far beyond environmental considerations to include economics, culture, crime, and entertainment. They go on to explain that with projects the goals can be clearly set at the outset and performance matched against those goals. Whilst there is clearly many different approaches to defining sustainability based on different philosophical backgrounds, practicing requires the selection of an approach and its application within a particular context. The context of this research is in the design of the built environment, which is typically done through projects and therefore this section explains and critiques the methods currently used in the building industry.

On building projects, legislation and regulations play an important role in driving more sustainable design and construction. However its role in more sustainable building design is not covered in depth in this review. This does not dismiss the importance that standards and regulations have in improving building performance with respect to setting minimum standards (especially with respect to aspects such as carbon emissions). Broadly speaking legislative mechanisms can be split into regulatory (minimum standard) methods such as Building Regulations and voluntary best practice standards such as BREEAM. For example the UK government has targets for all homes to be zero carbon by 2016 and all other buildings by 2019 (Department for Communities and Local Government, 2012). Although it should be noted that the definition on zero carbon does not include non-regulated emissions which can be a significant percentage in new buildings (Zero Carbon Hub, 2011).

Reasons for not going into depth on regulation are that designer’s influence is generally at a project level rather than a national policy level. Whilst having to achieve the minimum standards as imposed by building regulations, they are not in a position where they can lobby for an improvement in such national regulations through their work. However, designers are in a position to improve significantly on minimum standards through their work on individual projects through working closely with their clients. Furthermore, legislation varies from country to country and a comprehensive review is outside the scope of this research. At present they do not cover many aspects that would be viewed under the header of sustainability. Brandon (1999) points out, *“some of the requirements for sustainability will be found in legislation (which will demand a satisfying of certain standards), but not all.”* Therefore, rather than focusing on regulations, this research instead will focus on methods that can improve upon best practice voluntary techniques to improve the sustainability of buildings and in doing so significantly improve upon the performance with respect to building regulation, which does not cover the majority of social or economic considerations. This review therefore first focuses on Building Environmental assessment methods as they have been identified as best practice in environmental design and management (DEFRA, 2012). The general methods are critiqued but an in depth summary of what they include (for example the categories that they make assessments under) are not covered here (a summary of three environmental assessment methods in relation to roofs are covered in Section 3.4). Also considered are approaches which seek to understand quality and value of buildings as these aim to capture performance in complex areas which share some of the characteristics of sustainability.

2.3.1 Building environmental assessment methods

There has been a boom in the building environmental assessment techniques for evaluating the greenness of buildings. These span from very detailed life cycle assessment methods which account for the operational and embodied impacts of building materials to higher level environmental impact assessment methods which evaluate the broad impacts of a building on its environment. In between these extremes are building environmental assessment methods such as Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) (Crawley and Aho, 1999). Cole (1998) defines building environmental assessment methods as, *“techniques developed to specifically evaluate the performance of a building design or completed building across a broad range of environmental considerations.”*

The key features of building environmental assessment methods are shown in Figure 2—2. The 'assessment' module is the stage at which performance scores are assigned to various environmental criteria based on information provided in the 'input' module. This tends to form the major part of the discussion of assessment methods. The 'output' model is concerned with communicating the results of an assessment. This normally involves weighting of criteria to reduce a very large number of performance criteria into a smaller number of criteria. This is then combined into an overall score. This then links back to the information contained within the input module and through it back to strategic decisions in the building design or management as show in Figure 2—3.

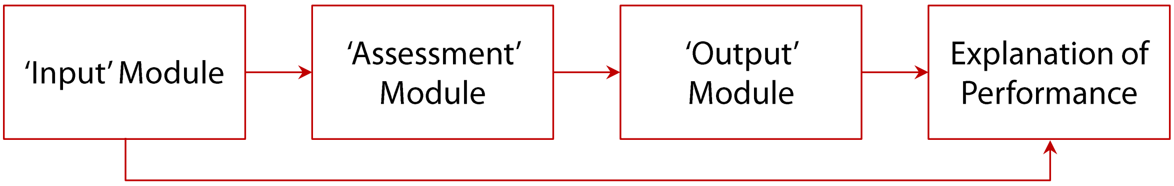


Figure 2—2 Key Features of assessment method after Cole (1999)

Cole (2005) explains that the technique may be accompanied by third-party verification before issuing a performance rating or label. The first such technique to be developed was the Building Research Establishment Environmental Assessment Methods (BREEAM). Developed in 1990 in the UK this was the first system to offer an environmental label for buildings and has now been used on over 200,000 projects globally (BREEAM, 2012).

BREEAM analyses building's environmental impacts in a number of key areas on internal, local and global levels by awarding points in a number of categories (Harris, 1999). Each system includes assessment ('assessment' module) under different categories ('input' module) and involves some sort of weighting of each category ('output' module). The results of each category are then compiled into a single score and a rating accordingly. The respective score is then given (explanation of performance). A schematic of the BREEAM categories and weighting process is given in Figure 2—3. The weightings for BREEAM were set following consultation with a variety of construction industry stakeholders including academics, construction industry professionals, lobbyists and scientists (Saunders, 2008). However, they do not include weightings from project stakeholders, or context specific weightings from an extended peer community. One could argue that the approach is expert driven rather than considering facts and information from an extended peer community of non-experts, with local specific knowledge.

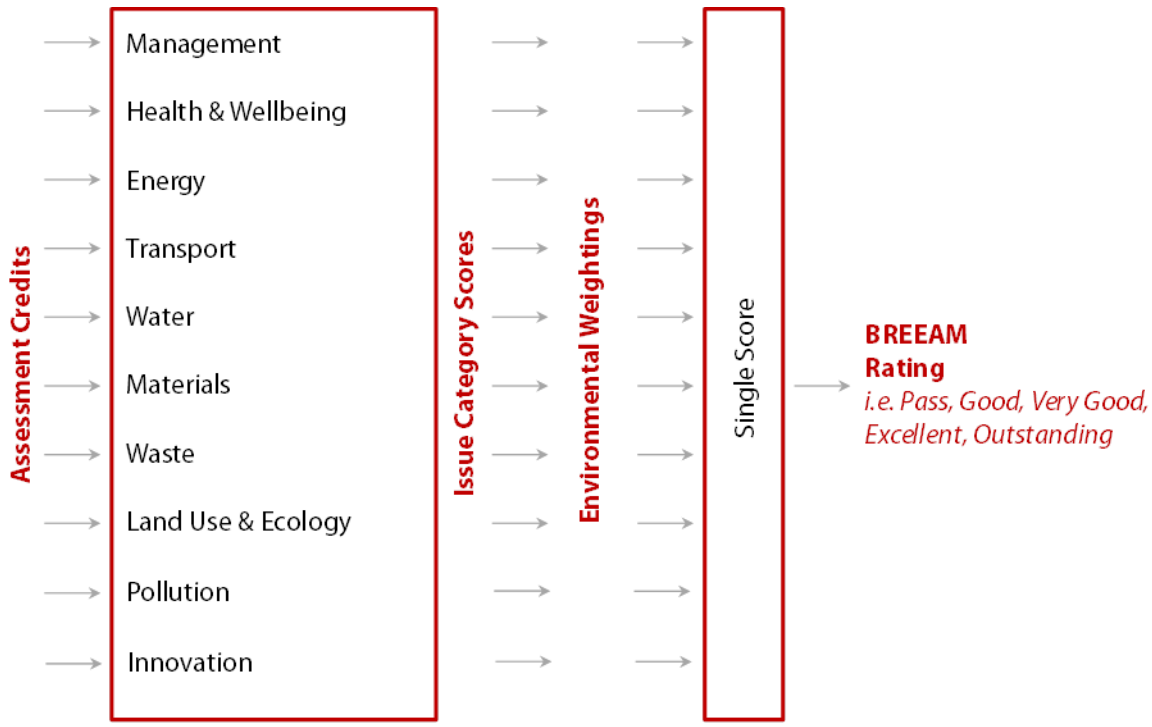


Figure 2—3 BREEAM scoring and weighting for non-domestic versions after Saunders (2008)

The process shown in Figure 2—3 is typical of most building environmental assessment methods in its process. Essentially all systems aim to aggregate a number of indicators, into an index to provide a score on the environmental performance of a building. The score may then correspond to a certain label or “badge”, i.e. BREEAM Excellent.

2.3.1.1 The growth and globalisation of building Environmental Assessment Methods (EAM)

Developments over time have also seen EAMs evolve in different ways to BREEAM (Saunders, 2008). There are now numerous systems around the world (see Figure 2—4). A table listing twenty industry used Environmental Assessment Tools, along with their origins, characteristics and references is documented in Ding (2008). Reviews and comparisons are available across the literature (Saunders, 2008, Haapio and Viitaniemi, 2008, Saniuk, 2011, Reijnders and van Roekel, 1999). Haapio and Viitaniemi (2008) categorise a number of environmental assessment approaches by the type of building they assess (i.e. existing building, new building, refurbishment etc.), users of the tools (investors, building owners, consultants, residents, building surveyors, etc.), phases of the life cycle (production, construction, use, maintenance etc.), the database that they use, and the forms of the end result. However what this section is concerned with is the general considerations of these tools and their approaches.

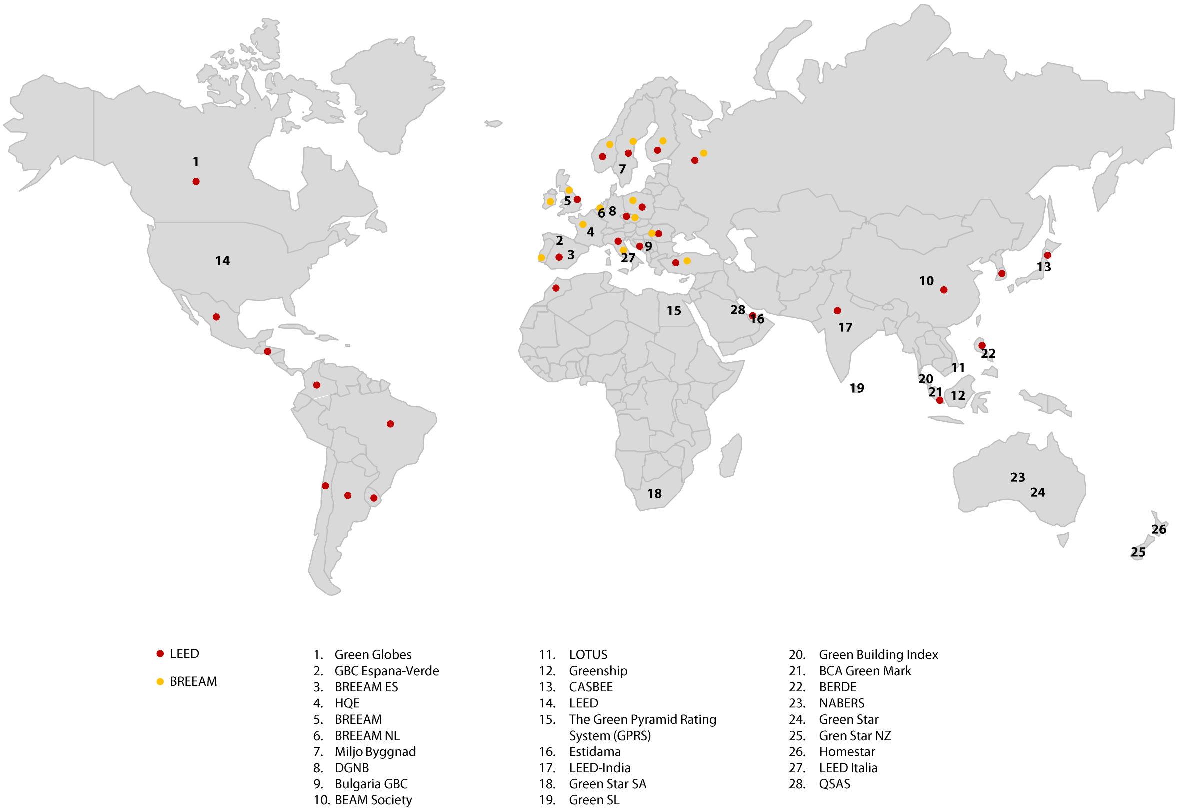


Figure 2—4 A global map of environmental assessment methods after Saniuk (2011)

2.3.1.2 Indicators and indexes

All environmental assessment methods discussed above are made up of indicators which are typically aggregated into an index. This section explains some of the generic literature on the subject area of sustainability indicators, indexes and frameworks is extensive. It should be noted however, that it is still very much a developing field. There is a multitude of different indices that measure the various aspects of sustainability. In fact, entire books have been devoted to the subject of sustainability indicators and methods of developing them (Bell and Morse, 2010).

An indicator is a simple measure that quantitatively represents a state of a system (Ness et al., 2007, Mayer, 2008). They have been used in a vast range of fields in order to measure, assess and plan different actions (Nardo et al., 2005, Bell and Morse, 2010). Bell and Morse (2010) suggest that indicators have probably been used for thousands of years and give the example of simple indicators of soil fertility, such as colour and presence of certain species.

Indicators allow for the tracking of sustainability trends if they are continuously measured and compared with past values. An index is a quantitative aggregation of many indicators and can provide a simplified, coherent, multidimensional view of a system (Mayer, 2008). Sustainability is an integrative concept, therefore it is reasonable to design sustainability assessment as an essentially integrative process and framework for decision making (Gibson, 2006).

Indexes can also be termed Composite Indicator/Index (Gasparatos et al., 2008). It is recognised that most indexes that are presently in wide spread use only tackle one facet of sustainability; economic, environmental, or social. Very few indexes integrate their approach to consider all three (Singh et al., 2009). Whilst Singh, Murty et al. (2009) offers a high level look at numerous indicators, Ding (2008) provides a more in depth look at industry used environmental assessment tools that are relevant to buildings (and therefore roofs). It should be noted here that at present in the building industry, there are relatively few frameworks in place that consider all aspects of sustainability, however there are many that consider the environmental impacts of buildings.

Indicators provide snapshots of a given situation at a given time. Indicators do not consider the time dimension in their own right. They are therefore only useful when used as a comparison for different products for a particular moment or for the progression of a situation over a time period. The progression is measured by using the same indicator at set time intervals. This is largely done for the economic indicators on an annual basis, often even reduced to a period of 3 months in many companies to correspond with their quarterly reports (Mayer, 2008).

Bell and Morse (2010) explain that a major criticism of Sustainability Indicators (SIs) is that they attempt to encapsulate complex and diverse considerations in a set of relatively few simple measures. This they argue is an obvious approach as it deals with the world in more manageable bits. This is nevertheless a reductionist approach, which is heavily critiqued across the literature (Gasparatos et al., 2009). Reductionism tends to involve quantification of systems and their performance, so that they can be tracked and modelled more easily. This is not a consideration unique to sustainability and has been done by scientists and policy makers for a long time on a range of issues. It is synonymous with the scientific 'positivistic' approach. This may have led to the common perception that scientists, policy-makers and others are obsessed with quantification. Indicators that consider multiple dimensions of sustainability (i.e. environmental, economic and social) are termed composite indexes. Three central steps are usually undertaken to compile composite sustainability indexes, these include normalisation, weighting and aggregation of indicators. All three steps are problematic in some sense. Some of these problems arise from employing objective methods to assess sustainability, which is very open to subjectivity in terms the choice of components and the weighting given to each indicator (Singh et al., 2009, Hueting and Reijnders, 2004, Singh et al., 2007). For this reason some authors argue that the aggregation of indicators from different dimensions is often meaningless (Hueting and Reijnders, 2004). These limitations are now discussed under the following headings. It should be noted that these limitations are true with any form of decision attributes and quantitative values used in multi-attribute decision making techniques.

2.3.1.3 Normalisation and weighting methods

Normalisation and weighting methods are generally based on subjective judgements which reveal a large degree of arbitrariness without explicitly stating the critical assumptions (Singh et al., 2009). Normalisation is the process of making different impacts dimensionless, so that they can be weighted and added together (Anderson et al., 2009). Weighting is the process of giving an importance to each indicator / attribute by giving it a value that represents it's importance. Often credit-weighting is at the heart of all assessment schemes since it will dominate the overall performance score of the building being assessed (Lee et al., 2002). Whilst weighting is clearly important, it is often difficult to decide how to derive the weightings and the manner in which the weighting process affects the interpretation of the aggregated result (Cole, 1999). Some indexes weight indicators equally, but problems arise when there are more indicators for one aspect than others. A greater influence is then given to that category with the most indicators (Mayer, 2008).

Weightings can be given on the basis of sustainability experts or opinions of the stakeholders within a system. This methodology considers the ‘world views’ of different stakeholders. Singh, Murty et al. (2007) argue that *“indicators of sustainable development should be selected and negotiated by appropriate communities of interest”*. However, indicators that are weighted by stakeholders can be problematic as long term environmental sustainability is *“not a matter of world views but of its actual fate”* (Hueting and Reijnders, 2004). This reflects peoples’ philosophical stance on sustainability, such as positivistic or normative as discussed in Section 2.2.2.

Others also disagree with the notion of individuals applying their own weighting as when an individual user of a sustainability appraisal system is allowed to apply their own weightings this is often done subjectively meaning that comparison between the results is difficult (Ding, 2008). However, some would argue that sustainability is related to the context and comparison may not necessarily be important.

The weighting process is also influenced by the required outcome of the assessment framework, for example, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) the Japanese equivalent to BREEAM, applies a weighting system that is extremely complicated and whilst their complex weighting system gives more flexibility it also leads to a greater potential for confusion and lack of clarity (Saunders, 2008).

2.3.1.4 Aggregation

Indicators can be combined into indexes in many ways. Whilst adding up the indicators is arguably the most simple and transparent way of combining indicators across different dimensions, it may not reflect the overall sustainability conditions. This is due to the complex relationships between the different dimensions of sustainability. Also adding together different indexes which use information from the same source (as is often the case in sustainability indicators) can skew the output as this could be classed as double counting (Mayer, 2008). Furthermore, the type of aggregation will have a significant impact on the scores. This can be highlighted by the different results that geometric and additive aggregation can have. A set of different aggregation techniques is included in Nardo et al. (2005)

2.3.1.5 Data inclusion

Indices are problematic if data is unavailable for the majority of the aggregated indicators (Mayer, 2008). Data inclusion also becomes an issue if there are gaps in the data or the data is of poor quality. In this situation the analyst is required to decide whether to drop data or construct missing data (Singh et al., 2009). Both of which could have a significant influence on the final aggregated score of the composite indicator.

2.3.1.6 Conflicting goals

The additive character of many composite sustainability measures does not show the conflicting nature of the constituents. Conflict and uncertainty are two of the biggest challenges when approaching environmental decisions (Gough et al., 2004). For example, there is an undeniable tension between the wishes regarding production in the short run and the wishes for safeguarding vital environmental functions in the long run; in order to attain a sustainable production level that does not jeopardise the living conditions of future generations. Adding these contrasting elements together to form a single overriding sustainability indicator conceals the difficult choices required to be made (Hueting and Reijnders, 2004). Techniques such as Cost Benefit Analysis (CBA) have been argued to obscure the impacts of different courses of action leaving decision makers less well informed rather than the reverse (Hammond and Winnett, 2007).

2.3.1.7 Advantages and limitations of building environmental assessment methods (EAMs)

Cole (1998) explains that environmental assessment methods have increased the scope of considerations to extend beyond just energy use, and in doing so they have made an immense contribution toward our understanding of the broader notion of whole building performance assessment. The varying roles, intentions and advantages of environmental assessment methods are described below (Cole, 1998):

- Provide a common set of criteria and targets so that developers striving for higher environmental standards can demonstrate their effort.
- Gather and organise data detailed information on the performance of a building which can be used to lower operating costs and improve performance.
- Be used by current building owners to identify priorities for future building retrofits which will keep a property current in a changing market place.
- Offer a means of structuring information for new building designs in a field which is rapidly expanding in knowledge and provide reference against which design teams can formulate effective design strategies.

- Facilitate the integration of environmental issues into practice through the creation of a body of knowledge and expertise within building design.

However Cole (1999) also outlines some of the limitations of Environmental Assessment Methods as follows: Cole (1999)

- Inability to offer different levels of assessment output (i.e. difficult to expand or simplify depending on the level of assessment required, i.e. high level concept vs. detailed design). This has now being reflected in some of the EAM such as BREEAM that now have pre-assessment calculators to estimate likely scores.
- Inability to acknowledge regionally specific environmental criteria (i.e. not designed to accommodate national or regional variations such as climate).
- Use of different measurement scales for different criteria sets (i.e. no clear or logical way for how the maximum number of points is assigned).
- Few of the existing methods use an explicit weighting scheme to acknowledge the relative significance of different performance criteria. It should be noted that this has changed significantly in the period since Cole (1999).
- They are being used as design tools when they were not designed to do so, this could be problematic as it could focus the design too narrowly on these aspects.
- Ability to link with other performance issues (Existing methods were developed to explicitly address environmental issues with very little reference to other building performance concerns).
- Ability to evolve as the field matures (an assessment of building performance has a limited shelf life as apart from reissuing updated performance criteria there is no method of dealing with the evolution of performance standards).
- Remaining voluntary in their application (meaning that they must provide an objective and sufficiently demanding metric to have credibility within the environmental community, while simultaneously being attractive to building owners who want to have something positive to show for their efforts). Additionally if something is voluntary, a detailed breakdown of the performance in individual categories cannot be accessed as the results may remain confidential. However, Cole (2005) recognises that this has changed significantly over the period between 1999 and 2005 and that they have moved beyond voluntary market place mechanisms. For example, performance thresholds in the assessment methods are increasingly being specified by public agencies and other organisations as performance requirements.

Environmental assessment methods do not typically include social and financial aspects in the evaluation framework (Ding, 2008, Cole, 1998, Cole, 1999). They therefore may not align with the ultimate principle of a project, as value is typically an important consideration (Austin et al., 2005b). Environmental and financial issues required consideration in parallel on projects and therefore Ding (2008) believes that they should be considered together. Additionally as they do not consider issues other than the environment, they cannot be classed as sustainable assessment methods (Cole, 1999).

Cole also explains that if environmental assessment methods were to be set within the context of ‘sustainability’, their emphasis would be conceptually different; currently they are based upon the concept of improving environmental performance above that of a baseline which generally represents that of the typical performance of a building (or regulatory minimum standards) (Cole, 1998, Cole, 1999). They currently assess performance relatively. Sustainable assessment methods would instead focus on measuring the absolute impact or stress that building design and operation place on ecological systems (Cole, 1999). In doing so they would ensure that it is within the assimilative capacity of the local and global ecosystems (Cole, 1998, Cole, 1999) and therefore take a strong sustainability stance based on positivistic scientific understanding. This is also support by Kohler (1999) who states that assessment methods based on relative performance hide the real mass and energy flows which determine the effective environmental impact and the differences in impact between individuals and different countries. Cooper (1999) also states unless methods for assessing the built environment are capable of measuring performance against this carrying capacity criterion, their ability to contribute significantly to the debate about ‘environmental’ sustainability is limited.

However, Cole (1998) does recognise that aspects built upon absolute sustainability would require an extensive understanding and quantification of the complex links between building decisions and ecological loadings. He emphasises that this will not be attainable in the foreseeable future and may never be completely possible. Such approaches assume that we have a good scientific understanding of what the absolute goal may actually be and therefore is approaching the sustainability angle from a ‘strong’ sustainability / scientific perspective. However (Cole, 2005) reflects on his 1999 paper and in doing so considers the changing roles and intentions of EAMs. He considers both normative and positivist sustainability. For example in reference to Robinson (2004) he states that ‘scientific analysis can inform but not resolve the basic questions posed by the concept of sustainability’. He considers both the anthropocentric (focused on aspects of the triple bottom line) or biocentric focus (placing environmental limits as paramount importance) of EAMs. He considers other approaches such as the Design Quality Indicator, DQI has a strong anthropocentric focus whilst techniques such as ecological footprint and LCA have a much more biocentric focus. Interestingly his stance has changed from one of following ‘strong’ sustainability to reflect a more normative approach where dialogue is encouraged. In fact, Cole (2005) lists that encouraging dialogue is an indirect benefit of using environmental assessment methods and also *“a more fundamental and perhaps primary future role is how they can transform the culture of the building industry to accommodate sustainability as a common, consistent and integral part of its decision-making. Given the broad range of perspectives and stakeholder interests contradiction and conflict is inevitable.”* Therefore how to manage stakeholder input and allow issues of importance to them and their context to be input into decision making with respect to sustainability is a key issue for the future development of sustainability assessment methods.

More recent papers also call for assessment systems to consider place and place based engagement (Kibert, 2007, Mang and Reed, 2011).

2.3.1.8 The changing roles of building environmental assessment methods

Cole (2005) says how the role of environmental assessment methods are changing from one of implied objective and accurate assessment to one of encouraging sustainability and the engagement of stakeholders in the process. A key question that emerges is how to engage stakeholders without undermining the process? Following on from this he explains how a huge amount of research has been focused on the ‘product’ aspect of building environmental assessment methods, for example improving the performance of their technical features. Whilst, it is generally recognised that environmental assessment methods’ criteria must be organised in a way to facilitate conducting an assessment, the structuring of criteria has significant implications for the output of performance evaluation. As Cole (2005) states;

> *“It is at this stage that the complete performance profile of the building is evident and the ‘story’ of the performance must be told in a coherent and informative way to a variety of different stakeholders. That stated, relatively little consideration has been given to this and other ‘process’ aspects of assessment methods or, more importantly, to how the structure of assessment methods facilitates dialogue between different stakeholders in formulating and pursuing a design project.”*

Two aspects have been gaining growing interest and these include (1) stakeholder engagement and participation in the use of EAMs, and (2) focusing on the process aspect of assessment. This has been considered by Kaatz et al. (2005) who argue that building assessment tools are increasingly being used to assess and encourage sustainability in buildings and that this can only be meaningfully achieved through fostering effective participation. Techniques recognised as best practice in this area of stakeholder participation according to Kaatz et al. (2005) include the, Design Quality Indicator (DQI) (Gann et al., 2003) and Post-Occupancy Evaluations (POE) (Cooper, 2001).

DQI is an assessment tool for evaluating the quality of buildings (Whyte and Gann, 2003). It seeks to complement existing techniques for assessing performance in construction by capturing the perceived quality/value of design from a stakeholder perspective (Gann et al., 2003). It sought to do this through measuring the perceived quality of the building which is difficult due to quality having both objective and subjective components. It consists of three main elements, these include, a conceptual framework, a data gathering tool and a weighting mechanism. Their approach was based on the premise, that the most important measure in a building's quality is whether it satisfies user requirements and what users think and feel about it. The scoring for each question and weightings of importance for the overall categories were all based upon the user opinions as elicited through a questionnaire. This asks questions in three areas (Gann et al., 2003):

1. **Function,** which includes three subsections, use, aspects and space;
2. **Impact,** which contains four subsections, form and materials, internal environment, urban and social integration, and character and innovation;
3. **Build quality,** which contains three subsections, performance, engineering systems and construction.

These areas are significantly different from the environmentally focused categories that usually form EAM, which normally include aspects such as energy and carbon, water use, ecology etc. What is interesting is their approach to user assessment and the ability to be able to do this at any time in the design process or after construction. Additionally, whilst the categories are assessed, the users are also free to weight the categories as they seem most appropriate for the building. In doing so (Gann et al., 2003) outline that this becomes less of a tool for objective measurement but more of a 'tool for thinking'. They explain that tools such as the DQI can be conceived as either tools for thinking or rational, objective measures. They state that the DQI is a, *"useful starting point for discussion and whilst it cannot provide an absolute measure of design quality of a building, it can be used to articulate the subjective qualities felt by different stakeholders in the design process and in the use of the building."*

POE is another method that has recently tried to seek user opinions and engage stakeholders in its process. POE typically focuses on assessment of client satisfaction and functional ‘fit’ with a specified space. Therefore the criteria for judgement are the fulfilment of functional programme and the occupants’ needs (Zimmerman and Martin, 2001). POE is based on the premise that the predicted performance of a building does not necessarily reflect the in-use performance of a building. Therefore it is important to go back and understand the differences so learning can be incorporated into future designs and projects and maybe improve the performance of the as-built building. However the scope of the POE is important and has sometimes just reflected that which is possible to measure objectively, such as energy use, as detailed in the CIBSE TM22 Methodology (Field, 2006) or the technical performance as outlined in the Probe methodology (Bordass et al., 2001a, Bordass et al., 2001b).

However, holistic performance is also important and is also incorporated in the Probe methodology to incorporate an understanding of the building users’ opinions (occupant perceptions) on the building (Leaman and Bordass, 2001). This form of holistic performance is then summarised and implications for design and procurement are given in Bordass et al. (2001c). Recommendations are also made for the design and handover process and conducting POE through approaches such as ‘soft-landings’ so that the ‘supply side’ of buildings such as designers, architects, engineers and construction professionals are more involved with users and the careful assessment of performance in use (Way and Bordass, 2005). A portfolio of feedback/POE techniques is presented in Bordass and Leaman (2005) and shows a range of techniques which span from objective measurement to subjective assessments.

Both POE and DQI provide ways of collecting feedback from stakeholders and using this information to improve the performance, quality or value of buildings (Kaatz et al., 2005). Kaatz et al. (2005) suggest that these approaches imply client and user participation in informing a design brief as well as evaluating a design. It follows that this requires a means of incorporating participation of users within the building project set-up. Many authors outside construction have argued that sustainability should incorporate stakeholder engagement and participation as questions such as what “ought to be” cannot be answered by technical means alone (Ratner, 2004, Robinson, 2004, Bell and Morse, 2010). This also reflects some of the principles of post-normal science as outlined by Funtowicz and Ravetz (1993), who refer to the need for an ‘Extended Peer Community’ (EPC). This requires user participation and stakeholder engagement. Currently EAMs do not provide means of facilitating stakeholder engagement and capturing the thoughts and opinions in a coherent manner and integrating these into project decision making. Additionally, even tools like the DQI, which utilise questionnaires and ask users to outline their thoughts with respect to the various questions as grouped into several categories, do not ask the relative importance of different questions. A weighting is given to the overall category. However, one has to ask how aspects that are not covered in this questionnaire are accounted for and how are these brought into the debate. How do these questions relate to the underlying needs and values of the project? Additionally, DQI is not without its critiques. Markus (2003) suggests that the DQI is no longer a measuring tool but instead a tool for guiding dialogue. They agree that this is a valuable way to improve the quality of buildings but continue to argue that, “if informed dialogue is the primary aim, much of the numerical paraphernalia (scoring, weighting algorithms, etc.) can and should be abandoned and the evaluative component enriched. Further critique is given as users are asked to score areas of performance according to their perception. Whilst this is required in some areas as more objective measures are not available, where more objective measures are available (for example, in relation to energy consumption of the building), this is seen as inappropriate.

Cole (2005) questions the emerging role of assessment methods and their need for accuracy and precision. He explains that the development of EAMs is not simply a case of introducing more rigorously developed criteria. Instead he argues that it's about recognising fundamentally different assessment cultures. Those that are *'uncompromising in their search for accuracy and precision in describing and reporting results, and those that are shaped by the reconciliation of a number of stakeholder interests.'* He argues that the purpose to the tool is critical to what level of accuracy is required. For example, if the purpose is to initiate interest or provoke green building activity, so long as it points the user in the right direction, precision may not necessarily be critical. However if the tool is to be used to inform policy decisions based on comparisons then accuracy is important for creditability.

Environmental assessment method categories and weightings are normally selected by a group of industry stakeholders, which in the case of BREEAM included academics, construction industry professionals, lobbyists and scientists (Saunders, 2008). This means that they define what is important across a range of issues and award achievement in these areas. This is done once and may be reviewed periodically. The weightings are therefore independent of the actual context of the projects in which it is being applied. Such systems therefore do not have the ability to acknowledge regionally specific environmental criteria (Cole, 1998). The fact that the categories and weightings may not reflect what is important in the context of the project may lead to a limited definition of environmental issues being pursued in order to achieve a high-performance score even if this is not appropriate within the context of the project (Cole, 2005). This can lead to ‘points chasing’. Other consequences of such approaches may be ‘gaming’, whereby design teams explore the requirements within an assessment system for interpretations that will yield the greatest score for the least cost. If these do not reflect the priorities of the project then this will not necessarily contribute to the greatest environmental benefit or indeed project value, rather just a high score in the assessment system. It is difficult (if not impossible) to capture all possibilities and assessment contexts in a fixed set of assessment criteria and therefore it is important to allow for flexibility and adaptability (Kaatz et al., 2006). As de Blois and De Coninck (2008) explain, design decisions are highly context dependent, and context is closely linked to time and space, it is difficult to plan for every alternative in advance as many variables will change. Including the stakeholders in the definition of criteria for each project and their associated weightings would mean that in order to score high ratings with respect to the design, the designers would have to consider the needs and priorities of the project rather than generalised considerations of a group of experts, which may or may not reflect sustainability considerations of a particular location or context.

Other criticism around the nature of EAMs or sustainability assessment methods are that they do not pay sufficient attention to the selection of more environmental friendly designs at the project appraisal stage which is when environmental matters are best incorporated (Ding, 2008). Kaatz et al. (2006) even state that sustainable construction requires more than green building environmental methods were ever conceived to do, as it challenges the very basis of decision making, which occurs during the building process, so that decisions taken by building stakeholders reflect sustainability values and principles. How such methods could more effectively inform sustainable design decisions is highlighted as an area for further development (Haapio and Viitaniemi, 2008).

Other, more recently highlighted criticisms include criteria of assessment systems in some cases being interdependent (Hiete et al., 2011). This can lead to double counting or provide criteria which are easily achieved on meeting other criteria. The potential for gaming is therefore increased.

Whilst some techniques that focus on decision making in the design process are evident, they are generally very quantitative and not-necessarily very transparent. For example San-José Lombera and Cuadrado Rojo (2010) use a systems approach to environmental sustainability integrated into the building design process, where they use techniques such as Analytic Hierarchy Process (AHP) to assign sustainability weights to different categories. However, their approach is highly quantitative and does not explain how such weights will be decided. Additionally, how performance in different categories will be assessed is also very ambiguous.

Whilst many building assessments assess what can be measured quantitatively, this author believes that in doing so many are falling victims of *McNamara's fallacy* outlined by Handy (1995):-

- Measure only what can be easily measured;
- Value arbitrarily what cannot be measured easily (artificial and misleading);
- Presume if it can't be measured it is not important (blindness);
- Or if it can't be measured easily it doesn't exist! (suicide).

This is a feature of many of the environmental/sustainability related assessment techniques. A review of the different forms of measurement and their adjustability to reflect local contexts, whether they possess a readable and flexible process, have quantitative and qualitative indicators and whether their scores are distributed according to their importance is shown in AlWaer et al. (2008) and highlighted in Table 2—3.

Table 2—3 Assessment procedures for each assessment method modified from AlWaer et al. (2008)

Measuring Tool		**Characteristics**						
Method Name	Year	Environmental	Social	Economic	SIs can be adapted in different regions - flexibility	Using a readable and flexible process	Quantitative and qualitative indicators	Scores distributed according to their impacts and importance of SIs
CASBEE	2002 2007	X X	-	-	No No	Yes Yes	Quantitative	No
BREEAM	1991 1993 1998 2007	X X X X	- - - X	- - - X	No No No Yes/No	No No No No	Quantitative	No
AIIB (Asia)	1992 2007	X	-	-	No	No	Quantitative & some Qualitative	No
Green Star	2003 2007	X	-	-	No	Yes	Quantitative	No
GBC	1998 2000 2002 2007	X X X X	- - - -	- - - -	Yes Yes Yes Yes	Yes	Quantitative	Yes
LEED	1998 2007	X X			No	No	Quantitative	No
The new proposed SCRSC model	2007	X	X	X	Yes	Yes, transparent system	Quantitative and Qualitative data	Yes
DQI*	2003	X	X	X	No	Yes	Qualitative	Yes
POE*	Various forms over many years	X	X	X	Yes	Yes	Quantitative and Qualitative data	Yes

* added to table by author.

The choice of criteria and weightings are both subjective issues. Variations in weightings as applied by a variety of building professionals have shown to have a significant impact on the overall sustainability score (Alwaer and Clements-Croome, 2010, AlWaer et al., 2008). Expanding such approaches to include the weightings of wider stakeholders to inform the development of sustainability assessment systems is only likely to increase this variation further.

To address subjective but important issues, hybrid approaches are also emerging which aim to integrate techniques. In some cases approaches have merged several concepts such as group decision making, multi-criteria decision analysis and life cycle assessment techniques to elicit opinions on different sustainable design options (Wang et al., 2010). Alwaer and Clements-Croome (2010) describes a sustainable building as a complex system of inter-related issues which include People (owners, occupants, users etc.); Products (materials, fabric, structure, facilities, equipment, automation and controls); and Processes (maintenance, performance evaluation, facilities management etc.).

They therefore advocate a multi-method approach combining a literature review to identify a list of sustainability indicators and then engagement with professionals to develop and select Key Performance Indicators (KPIs) for design projects. The engagement with professionals is essentially to ask the question *“which of these issues is most important?”* Pair wise comparison was the method used to define the priority level of each KPI, which through the process was given a score between 1-10. A level of performance was judged subjectively on each KPI and given a score between -2 and 5 (allowing negative scoring) with descriptions accompanying each performance level score so stakeholders knew what each score represented. The overall sustainability scores were then calculated for each indicator by multiplying the performance level by the weighting.

This approach was undertaken across a range of architects, engineers and sustainability assessors. Sustainability assessors were experts who had extensive knowledge in assessing building performance. Points to note were that there was considerably more agreement when the experts assessed performance level (even though this was done subjectively) than on the priority level. Additionally the performance level could also be assessed objectively in many cases but weightings and expert weightings can only be assessed subjectively. The weightings can significantly skew the results. Alwaer and Clement-Croome (2010) recognise that this stems from the problem that understanding requirements and translating these into meaningful indicators is universal and one that many stakeholders have struggled with. This is highlighted in the DQI (Gann et al., 2003) and by others AlWaer et al. (2008). Alwaer and Clement-Croome (2010), explain that given the different weightings and scores given by different stakeholders, it would be meaningful to do trend analysis in real practice. This would include for example taking averages for each of the selected indicators and therefore the KPIs could become a consensus tool amongst stakeholders. This is outlined as a useful way to progress the work. They reflect that their approach could facilitate the process of recognition and incorporation of regional diversities. This would require a way to understand different stakeholder perspectives and an acceptance that subjectivity in sustainability is unavoidable as consensus needs to be reached by a wide variety of stakeholders. Additionally such approaches should be facilitated by whoever is carrying out the sustainability assessment.

Kaatz et al. (2005) present a theoretical justification for modifying sustainability assessment to include broader participation of stakeholders. They conclude that the very act of participation grounds the process and project in the local context and allows assessment to reflect the local needs, socio-cultural, economic and biophysical contexts. This is also shared by Mathur et al. (2008a), who also state that meaningful stakeholder engagement can be seen to enhance inclusive decision making, promote equity, enhance local decision making and build social capital. All these are essential for sustainability. They also promote the view that stakeholder engagement can also be an opportunity for social learning.

Kaatz et al. (2006) therefore focus on techniques to do this through understanding the process of building assessment methods and how stakeholders can be integrated into the process as opposed to just simply how building assessment influence the buildings as completed products.

There are several emerging themes from the increasing literature on the subject of sustainability assessment. These are summarised below building on a list developed by Kaatz et al. (2006):

- **Integration:** merging bio-physical, socio-cultural, political, economic and technical aspects of building development.
- **Integration of sustainable development principles:** foster the principles of intergenerational equity through stakeholder engagement in project level decision making; additionally consideration is given to carrying capacity, perhaps through instruments such as ecological footprint (Rees, 1992).
- **Integration of stakeholder values**: a key role is the integration of stakeholders' values, needs and preferences into the design, delivery, and operation of the built environment. Therefore in order to improve the relevance of the output of building assessment it is key that they provide relevant information at key decision points.
- **Integration of stakeholder knowledge:** the process of building sustainability assessment should accommodate the participation of professional and lay stakeholders. This should preferably take the form of collaboration, where stakeholders combine their efforts in the spirit of team work guided by a common project vision.
- **Transparency and accessibility:** with respect to developing the process, it is important that if methods are to respond effectively to the information demands of decision makers and to provide a credible and objective basis on which to base decisions and support building documentation and history building. It is considered that adequate transparency of the building process itself enables process verification which reinforces validity.
- **Access to information**: this is linked to process transparency and stresses the importance of stakeholders being able to access information during the assessment.
- **Communication**: linked to both accessibility and transparency as both can be improved by visual aids and the method of communication.
- **Collaborative learning**: as Robinson (2004) argues, sustainability assessment needs to be a participatory process fostered through social and collaborative learning. This requires participation and close integration with the building process. This also reflects authors who consider that it is important to 'learn' your way to sustainable built environments (Godfrey, 2010) or to indeed treat the whole concept of sustainability as a learning process (Meppem and Gill, 1998). Social learning is also a key theme in Mathur et al. (2008a).

- **Transfer of knowledge:** should enable the transfer of both explicit and tacit knowledge through collaboration and participation.
- **Enhancing commitment and learning**: if stakeholder participation is in the co-design of the building assessment process during scoping and if this promotes an integrated project delivery, then they are more likely to develop the necessary commitment to implement sustainability in construction.

The ideas summarised above reflect a growing consensus on required changes to building assessment systems to become more sustainable (Gasparatos et al., 2008). However, there is much less evidence on how this can be done, especially when applied to the design and construction of buildings. Whilst DQI and POE provide a start, techniques for broader inclusion of stakeholders to understand needs and values are less evident across the literature, especially with reference to design and construction.

One such article reviews several approaches used to understand values and discusses their potential application in the construction sector (Mills et al., 2009). This references many approaches from sociology and psychology in the review.

Others have also argued that the solution-space for innovation for sustainability is characterised by three dimensions which include; (1) the entire lifespan of a product; (2) the entire socio-technic network from which a product emerges; and (3) stakeholders and decision processes, including business organisations and strategies and public institutions, policy and regulator frameworks (Dijkema et al., 2006). Whilst it could be argued that none of these aspects are well considered in the building sector, this part of the research will focus on stakeholders and decision processes as one element to improve the sustainability of buildings.

Broader engagement techniques are not well covered. Additionally, methods of integrating environmental, social and economic performance are not typically well considered by building environmental assessment methods. Whilst DQI considers a broader spectrum, and its aim is to understand stakeholder opinions, it does so in areas that are not necessarily aligned with the environmental, social and economic elements of sustainability. Additionally, whilst a questionnaire is used to assess the performance, this is entirely based on user perceptions. Whilst for subjective elements this is considered appropriate, for more objective elements this could be misleading. Additionally, stakeholders cannot add further criteria to the framework which might be particularly important in a given context.

In order to better define sustainability and assess it in the project context, it is considered that an improved approach would take on board elements of environmental assessment methods that outline important considerations from an environmental perspective, but also allow a project's stakeholders to have a say in which criteria are important for the project. Essentially, it should take on board elements of both environmental assessment methods and other techniques, such as DQI and POE. Furthermore it should consider the emerging themes that are highlighted by Kaatz et al. (2006). Particular focus areas for this research will be in the following areas:

- Integrate social and economic value considerations
- Integration of stakeholder values.
- Integration of stakeholder knowledge.
- Improving transparency and accessibility.
- Improving communication.
- Collaborative learning.

Additionally, the focus will be how to define categories to inform decision making, rather than just assessment (which will be an important part of understanding the pros and cons of different options).

This section has reviewed techniques that consider sustainability in the building industry and specifically the design process. As an emerging area is to integrate social and economic value considerations, the next section will look at the relationship between value and sustainability, and how value is considered in the construction industry.

2.3.2 Value & sustainability

This section explores the relationships between value and sustainability. Value in construction is extremely important, and became prominent following the publication of the Egan Review (Egan, 1998) which looked at construction and highlighted how the majority of clients equated ‘price with cost’ and that most were selecting constructors based almost entirely on the basis of tendered price. It then recommended that, *“the industry needs to educate and help its clients to differentiate between best value and lowest price”*. This widely referenced report in the UK construction industry also considers sustainability stating that, *“too many buildings perform poorly in terms of flexibility of use, operating and maintenance costs and sustainability.”* Egan's recommendation was that there *“has to be a significant re-balancing of the typical project so that all these issues are given much more prominence in the design and planning stage before anything happens on site. In other words, design needs to be properly integrated with construction and performance in use. Time spent in reconnaissance is not wasted.”*

Following on from this Cole (2000) explains how a central concern of clients that spend money on green buildings is whether they get good value for their investment. Value is described by some as the ‘key goal of all projects’ (Austin et al., 2005b). Despite this, others suggest that value and quality usually take second stage in decisions regarding how and what to build (Gann and Whyte, 2003).

Bourke et al. (2005) repeatedly mentioned sustainability in relation to Whole Life Value (WLV) and describe tools to help the delivery of WLV such as LCC, LCA and MCA. Such tools are also referenced in much of the sustainability literature. Furthermore, CABE (2007) list six types of value, which includes, exchange, use, image, social, environmental and cultural value. This covers different timeframes (i.e. exchange and use) and also considerations that are often aligned to sustainability such as environmental, social and cultural. It therefore seems appropriate that value and sustainability should be considered together, rather than as separate entities.

Value, like sustainability, is not easily defined in the construction industry. However, *“value has traditionally been judged in terms of a limited range of considerations – location, quality, function and aesthetics”* (Cole, 2000). It could be argued that in construction the boundary of which value has been traditionally judged has been relatively tight, excluding the opinions of many of the project stakeholders and consideration of the whole lifecycle. This boundary of the value judgement has been dictated by upfront financial concerns, regarding capital cost to provide a ‘function’. The function itself may also not necessarily have been well defined.

Gann et al. (2003) state that, *“designers have long been interested in the overall value added through their efforts and the legacy of design decisions on future generations of users. Their ability to ‘prove the value of design’ has been elusive and is a problem not unique to the building and construction sector”*. This is because aspects such as quality and value straddles both hard technical systems and softer human (value laden) systems and thus is hard to quantify objectively .

In many cases questions arise as to whether all the stakeholders in today’s complex project environments share a common vision and understanding of “value”? The problem is often accentuated by individuals informing the design assuming that they each have the best view of what value is. This is highlighted in the following quote.

> *"Designers may be guilty of thinking they are the single best judges of value and so select building solutions against their own values, without a full understanding of all customers' priorities and expectations; Quantity Surveyors, while understanding detailed elemental cost break downs, may eliminate costs without a clear understanding of associated stakeholder benefits. Project Managers may quickly arrive at design solutions by minimising stakeholder involvement and Engineers may search for a functional solution, without an understanding of how they could achieve or even exceed stakeholder expectations. Clients may seek to reduce design spend and objectively specify design requirements that act as a constraint and limit design creativity. Whilst Value Managers may limit their definition of value to objective and functional criteria, eliminating more subjective cultural factors that define the very nature of the people affected by the project." (Mills, Austin et al. 2006)*

This highlights that different stakeholders in construction have different concepts of value (different viewpoints, mental models and belief systems). Their different viewpoints determine how they perceive a building's value and in turn influence their decision making. The outcome could be that different stakeholders make decisions that are contradictory, genuinely believing that it is in the best interest of the project. Consequently, in order to improve the current situation, *"the industry needs clear definitions of qualities, quality, value and values"* (Thomson, Austin et al. 2003). Without a clear definition of what represents value, the purpose and requirements of the projects are never made truly open and explicit, meaning that it's harder to deliver value for the project stakeholders.

To further complicate value delivery in the construction context, the current practice in the design of buildings usually results in information from users not being transferred to design teams in a shape and form that can be used for reconfiguring and improving upon design – either in a single building project or for subsequent projects. If it is available at all, information generally arrives either too late or in a format that cannot be used by front-line designers and engineers. These problems are exacerbated by an overly specialised approach to education and training of built environmental professionals (Gann, Salter et al. 2003).

The understanding of what value is in the construction context domain is important. The manufacturing sector has adopted an objective view of value for many years which has influenced their culture, processes and tools. For example value analysis in manufacturing involves the testing of functions required by customers as design objectives. This approach substitutes for the direct engagement of customers (to identify their values to which the design must respond). Whereas in the field of customer value management, value has been defined as quality (including all non-price attributes) relative to price and it is stated that quality, price and value are relative. Therefore the customer value field supports the subjective view of value (Thomson et al., 2003). Again this highlights the importance of the placement of boundary to how one might measure and deliver value.

Thomson et al. (2003) offer a good review of value through the fields of (1) Theory and philosophy of value, (2) manufacturing and product design practices such as value analysis, value engineering and lean manufacturing, (3) the recent emerged field of customer value management, and (4) construction management theory to develop an understanding of value that is useful in construction. This highlights that value can be judged objectively as either meeting a set of pre-determined requirements in an allocated time and budget. Or it can be judged subjectively by the feedback of customers/stakeholders.

The problem of measuring the value of a design and the subjective nature of value is well highlighted by the quote taken from the VALiD brochure (Austin, Thomson et al. 2010):

> *"Consider a scale of 1 to 10 on which the value of a building or project is expressed. The architect thinks that the building offers a value of 8, while the facilities managers and client think the building's value is 5 and 6, respectively. A person walking by on the street, meanwhile, thinks that the building has 4 units of value, yet his friend alongside him considers the building's value to be 5. Why are these opinions so different when the building is the same? Which one (if any) is right? How can the differences be explained, reconciled and used to inform project provision? How can project management accommodate these different points of view?" (Austin, Thomson et al. 2010).*

This is supported by Gann et. Al. (2003) who state *"there might be many different and conflicting views held by individuals and groups. Facilities managers, clients, occupants, visitors, cleaners, repair staff, etc. might all have different* perspectives *on the same facility."* Bordass (2000) also demonstrates how value can be judged differently from different perspectives utilising rich pictures of numerous stakeholder viewpoints on energy efficiency measures. Gann, Salter et al. (2003) explain that "t*he most important measure in any evaluation of a building's design quality is whether it satisfies* user requirements *and what users think and feel about it*. *However, understanding the views of users is not easy…"*

With respect to lifecycle, some stakeholders are typically not involved in certain parts of the life cycle of the building and thus they have little influence in things that could potentially have a large impact on them. For example, the occupiers will not typically be involved at the inception or feasibility appraisal part of the project (Bourke, Ramdas et al. 2005). Additionally value is rarely described in a project context**.** This is surprising given that it is this temporary environment that brings together organisations, disciplines and wider stakeholders with potentially divergent values systems and influences (Mills, Austin et al. 2009).

Additionally, value is rarely measured in the later stages of the project as Post Occupancy Evaluation (POE) is not common in construction despite "Feedback" being an official stage of the RIBA work stages since 1963 (Bordass and Leaman 2005a). The lifecycle performance of the building is not validated in terms of performance or often understood from the different stakeholders' perspectives. It is only relatively recently that POE has started to go beyond the measurement of the performance of hard technical systems, and started to include user behaviour and user comfort. A good summary of the benefits of feedback from POE and techniques available are included in the Probe series of post-occupancy surveys (Bordass and Leaman 2005a; Bordass and Leaman 2005b; Way and Bordass 2005). The learning from POE can inform future projects to better meet client expectations. Hence POE could be important in improving the delivery of value and sustainability on building projects. Unfortunately, this is not routinely done in the construction industry.

In summary, value is an important consideration of building projects. It is likely that sustainable features will have to be seen as good value for them to be decided important enough to be designed and constructed into the scheme. Unfortunately, value like sustainability is hard to define, but there is a growing consensus of the need to engage stakeholders and define the key objectives for the project and understand how sustainable features can be seen as good value. Techniques that have been used to define value in the project context however, such as the Value in Design (VALiD) Approach (Austin, Thomson et al. 2010) may also be useful in defining sustainability as both could be argued to be value laden concepts. For this reason, such techniques may offer valuable approaches to understanding sustainablity in the project context.

The following section of this review consider some of the challenges of the design process, which will have to be considered in the development of an approach and associated decision support tool.

2.3.3 Challenges of the design process

In order to understand the challenges of integrating sustainable decision making in the design process, this section reviews several papers and summarises a variety of considerations.

In order to give some context to the design process, Figure 2—5 details the RIBA Plan of Work (RIBA 2013). This is the standardised work stages for the construction industry in the UK for the design of buildings. Whilst it is accepted that this flow of work is not standardised across countries, there are many similarities between different systems used globally.

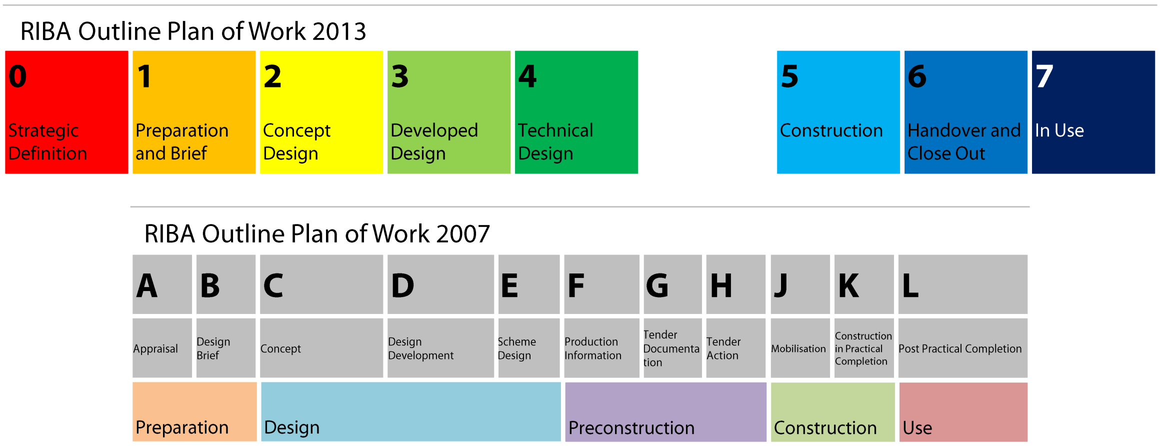


Figure 2—5 RIBA plan of work 2007 and RIBA plan of work 2010 after Mark (2013)

The opportunities for cost effective ecological design solutions are highest at the start of the design process, as shown in Figure 2—6 (Reed and Gordon, 2000, Gervásio et al., 2014). This is also supported by recent research that asked construction professionals to link sustainability criteria and when is the most important time for them to be considered in the design process (Kim and Park, 2013). Figure 2—6 shows the design team are typically selected well into the project and significant opportunity is lost prior to their selection for integrating cost effective sustainable solutions. What is referred to as “Schematic and Design Development Phase” in Figure 2—6 corresponds with Stages 2 / 3 of the RIBA 2013 Plan of Work. Therefore, of particular interest is how sustainable decision making can be integrated into the building delivery process, such that it can inform the earliest stages of design and even prior to this to inform the development of the projects objectives.

This section therefore considers some of the challenges of integrating sustainability and participatory methods in the project delivery process, from the earliest possible opportunity for the design team, in order to address the better integration of sustainability into the design process.

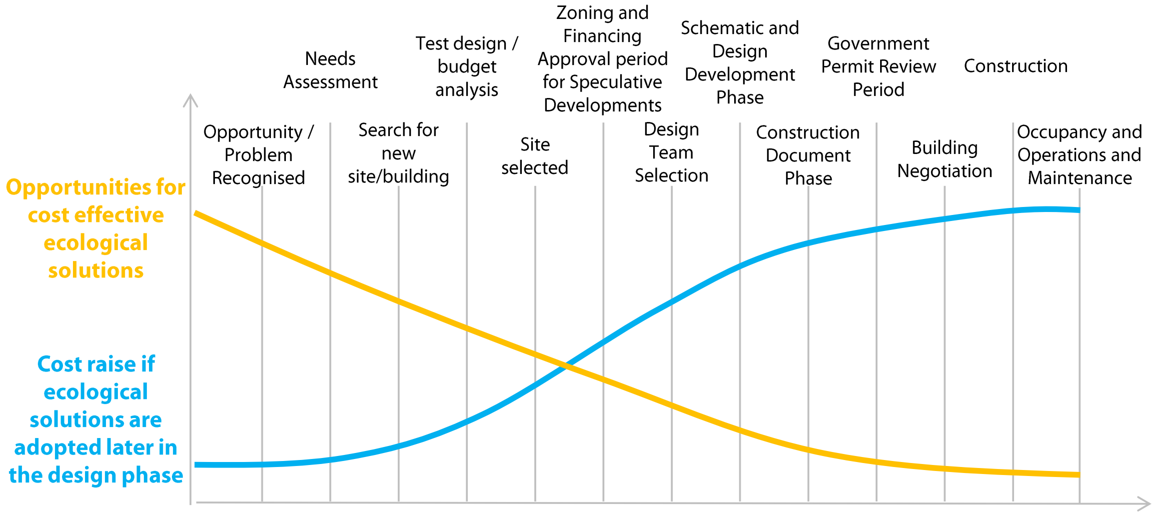


Figure 2—6 Relationship of cost and ecological design opportunity after Reed and Gordon (2000)

In order to structure decisions, clear objectives are required. The objectives of a project are typically contained within the project brief, therefore a clear brief is very helpful for the design team, as they can take this as requirements for which the design must strive to achieve. In order to achieve a sustainable project, the brief should be representative of the desires of the project’s stakeholders.

Often in the building design and construction industry, the objectives of the project are not necessarily well expressed or communicated. However, from a design team perspective the objective of the system is often taken as an absolute given and the problem therefore is reduced to one of technical efficiency (Green and Simister, 1999). This can be problematic as the design team may then focus on improving or optimising the wrong thing if the vision is not well defined and the objectives do not reflect the values of the project stakeholders. Additionally, the people that the building is designed for may not necessarily be considered in significant depth.

The need to consider multiple objectives and to address the concerns of diverse stakeholders raises particular difficulties in applying sustainable development principles to defining and choosing an optimum project, process, product, policy or solution (Elghali et al., 2008). Additionally, with respect to sustainability, decisions are required early in the design process and have a significant impact on future stages, including the life cycle performance of the building (Schade et al., 2011). Therefore, the outcome of a project can be significantly improved if the different design options can be rapidly assessed in relation to the project objectives. Therefore, decision making in the early stage of the process is highly important, and this has led to some stating that formal decision making processes are required at this stage (Kaatz, Root et al. 2005).

This point is iterated by Thompson and Bank (2010), who explain that in the early project stages, such as concept design, key decisions must be made when information about the final design and operation of the building or building system is unavailable, but the ability to affect the cost is the greatest.

Green and Simister (1999) explain that traditional systems engineering has failed consistently when applied to organisational problems which are messy, dynamic and ill-defined and that it is such problems which invariable distinguish the early phases of building design. This therefore makes ‘hard’ systems engineering, and by association the accepted process, unsuitable for the purposes of strategic briefing (Green and Simister 1999). Therefore, softer more stakeholder driven and social appraoches are required in the early strategic briefing of projects.

Reed and Gordon (2000) call for process professionals and a need to focus on how professionals interact to improve the building delivery process. The importance of improving the briefing process has long been recognised, however there has been little progress in the development and implementation of new methodologies. Green and Simister (1999) point out that the conclusions of the Latham report are very similar to those of the Banwell report published thirty years previously.

This is supported by Cole (2000) who states that, *“The research community has offered considerable knowledge on green buildings over the past couple of decades. However there are five areas which remain relatively uncharted (1) good robust information, (2) more than technological issues, (3) systems thinking and analysis, (4) understanding the process (5) good communication”.* Further to this Reed and Gordon (2000) state that *“there is currently insufficient research work underway in the commercial building industry that specifically targets the commercial building delivery and operations process. The traditional building delivery process and type of R&D that it relies on focus almost exclusively on the development of new technologies and equipment that can improve the overall quality of the building… To help mainstream green building design and construction practice, well documented case studies are required that demonstrate the process and benefits of sustainable design. Case studies documenting performance and cost are already being done by a number of organisations. What hasn’t been done are ‘process case studies.”*

Funtowicz and Ravetz (1993) explain that the concept of engineering in most routine engineering practice is a matter of empirical craft skills, which utilise the results of applied science. However as they continue, “at its highest levels it becomes true professional consultancy.” In response to this, many of the above authors share the opinions that there has been considerable focus on improving the routine engineering practice and utilising the results of applied science to achieve improved technical performance, but less focus on softer consultancy and the process based elements relating to the definition of the problem to be addressed in the first instance.

Failing to consider the whole process and the larger problem may lead to an optimal solution for an incompletely formulated problem, as opposed to a less-than-optimal solution of a completely formulated problem (Ackoff 1981b). This is what led Ackoff (1981b) to define the ‘design approach’ where a designer, “*makes use of the methods, techniques, and tools of both the clinician and research, and much more; but he uses them synthetically rather than analytically. He tried to dissolve problems by changing the characteristics of the larger system containing the problem. He looks for dissolutions in the containing whole rather than solutions in the contained parts.”*

For the above reasons, this research is focused on the development of approaches and decision making techniques, rather than focusing on developing further technologies. Process case studies will also provide examples of approaches, which can be applied in construction.

Cole-Colander (2003) explains from her reflection on designing the customer experience and from developing the Design Quality Indicator (DQI) that discussion and debate are vital if there are to be *'harmonious joined up aspirations for the built environment that can be subscribed to by all those involved in the construction industry."* Unfortunately, whilst many designers and engineers profess to be integrated systemic thinkers, they are often highly specialised and in reality the speed of the building process leads to isolated decision making and sub optimisation of nearly every system. This can lead to over-design, where buildings are designed either too specifically, or include unnecessary features. In such cases systems can also function in conflict with one another (Reed and Gordon 2000).

"Since a project's success relies upon the right people having the right information at the right time; proactive resourcing of stakeholder views should ensure that appropriate participants are consulted early in the process" Cooper et al. (1998) c.f. (Kaatz, Root et al. 2005). Therefore Kaatz, Root et al (2005), focus on an approach that serves the purpose of identification, definition and evaluation of client's requirements in order to identify suitable solutions.

Until recently, there has been very little emphasis on the process professionals, how they interact, and how the building delivery process can be improved. There is, however, a mainstream feeling in both industry and government R&D circles that without understanding the process, the effect of newly developed technology will be minimised by a fragmented and consequently uncooperative process (Reed and Gordon 2000). This is a significant problem with respect to value and sustainability, which require the integration of many systems to work in synergy to reduce costs and increase building performance. An integrated design process that enables integration of building, community, natural and economic systems through cross disciplinary team work is therefore a key to sustainable design (Reed and Gordon 2000).

Fortunately, the knowledge of the tangible and intangible benefits that arise from good design is growing. However, better information together with improved valuation methods and a new attitude towards evidence-based design are all needed if the built environment is to reflect the emerging understanding (Macmillan, 2006). In fact, outcomes of structured focus groups (Macmillan, 2006, Macmillan, 2005), that discussed valuation of the intangible, states how delegates of three structured focus group workshops *"argued that there was a need to open the "black box" of valuation and that there is clear potential to develop a methodology that could become a valuable tool to aid decision makers."* Macmillan goes on to state that the potential benefits include the following, *"better articulation of the values held by stakeholders, leading to more informed negotiations among them, and a greater likelihood of meeting expectations and valued outcomes, and better evaluations of alternative options, more appropriate levels of investment and improved management of buildings as assets, helping to ensure premises are well suited to the organisations that occupy them."*

In summary, the following are some of the challenges that are faced when trying to design more sustainable projects in the building industry.

- The design team is involved too late in the process to be able to influence sustainability at the earliest project stages when it is the most cost effective to do so.
- Unclear or contradictory objectives, often mean that designers do not know what they should focus their efforts on. This is emphasised in the lack of understanding of what represents good value.
- Designers often focus on optimising performance against incomplete objectives, rather than focusing on defining the most appropriate objectives.
- The design process is fast paced leading to isolated decision making, meaning integration across different systems and opportunities and trade-offs is not adequately explored.
- Failure to consider the whole process and larger problem, for example different specialists may focus on optimising their particular aspect, whilst not considering the broader implications for the project, potentially leading to sub-optimisation.
- The most influence is when there is typically the least information, meaning that decisions are based upon a limited amount of information, which may not be robust.
- Lack of integration and communication between all interested parties in the project.

- The need to consider stakeholders and recognise that different stakeholders will have different needs and perspectives. Engagement with stakeholders can be minimal for many members of the design team.
- Limited consideration of the life cycle performance of buildings, meaning that focus may not be on improving the performance over the design life of the building. For example, little consideration of the design life or efficiency of systems over the project's lifecycle.

The above issues have provoked a call from several authors for a focus on process and formal decision making approaches for the early project stages, new methods of evaluation of alternatives with an emphasis on evidence based design (Macmillan, 2006, Reed and Gordon, 2000, Kaatz et al., 2005, Kaatz et al., 2006, Cole, 2000).

These have to be considered through the development of an approach and decision support tool to inform the selection of more sustainable roofs. Additionally, this has informed the development of several engagement techniques which aim to address some of these challenges and provide key themes on which sustainable decision making can then be made. These are further considered in the discussion section of this part of the thesis.

Whilst the above points all represent challenges of the design process, these are all generic and a more focused consideration specifically to do with the challenges of more sustainable roof selection would be beneficial. This informed the action research, through which the researcher tried to inform roof selection for a large masterplan to identify challenges specific to this issue and better define the requirements of an approach to support sustainable roof selection. This original research is presented in Section 11.

2.4 Summary and research gaps

The literature review has covered the broad concepts of sustainability and the history and philosophical stance on which different interpretations are based. This covers the terms of sustainability and sustainable development and the backgrounds from which they were derived.

It covers different models of sustainability and different stances, which include, *'strong'* sustainability, which emphasises that natural capital cannot be substituted for other forms of capital and thus assumes that natural limits should constrain our actions. This is generally seen as a stance taken by Herman Daly (Daly, 1990). Weak sustainability is also covered, which assumes that natural capital can be substituted with other types of capital. This research, whilst acknowledging that strong sustainability is important, does not seek to look at the building and its various systems in this respect. Instead it will take a weak sustainability stance, accepting that the overall stance is aligned to the term weak sustainability, i.e. the substitutability of different forms of capital (i.e. social and economic capital for natural capital).

Therefore, the research will be aiming to increase the realisation of greater environmental, social and economic potential through roof selection than is presently delivered through current decision making processes. The choice to accept a 'weak' sustainability stance, is taken to limit the scope of the work, as the research will be set in an industrial context. Thus taking a "strong" sustainability stance, which places the natural environment above all else and does not allow for its degradation in return for social and economic gain, would be to some extent challenging economic growth and the associated underlying philosophies. This would be difficult to do from a consultant's perspective working for a client, who may have clear economic objectives, but with less clear environmental ones. Therefore, this is considered beyond the scope of this work in the industrial context. The research will focus on roof design and selection that is most appropriate from a Sustainable Development perspective i.e. balancing economic, environmental and social concerns.

Approaches to sustainability were then discussed. This considers positivist sustainability, which treats sustainability as based upon the application of scientific methods to define what is sustainable and what this means. However, from a scientific perspective, there is uncertainty in what the environmental limits or the carrying capacity of the earth is. Therefore, blueprints of what we need to strive for from a scientific perspective are not available with any degree of certainty. Adding to the complexity are the different interpretations of the concept of sustainability. It can mean very different things to different people. Additionally, whilst science is useful in moving our understanding forward, it is failing to address value based questions. These are deep questions into what is important to individuals, groups and wider society. Science can inform this debate, but can by no means lead it. This has led many authors to consider normative sustainability, which engages societies to debate the meaning of sustainability and to think about the question, *'what ought to be?'* Pragmatic realist sustainability, as defined by the author, takes a middle ground stance. This is considered holistic, in that it does not neglect either a positivist or normative perspective, but instead seeks to integrate the two.

This research takes a pragmatic realist stance and considers both a normative and positivist approach and that both can be used synergistically in decision making. First we need to define what sustainability is within a given context for a project. Secondly, we need to be able to justify decisions with quantitative performance data on the options, where we have this. Where we don't have quantitative information, we need to be able to make a judgement on the different options qualitatively. Therefore, the research will seek to take on board both elements of 'sustainability' via scientific, and normative approaches as appropriate. Additionally, this is required as scientific knowledge is unable to resolve differences in context at present in relation to the physical environment or the values of those involved with projects. Therefore, there is a real need to engage with the context. The project context is defined by this author to be the physical environment in which the project sits and the people who are likely to be involved or have a 'stake' in the project throughout its lifecycle from project inception, through to its 'in-use' phase and ultimately demolition. Additionally, this research is written from the perspective that regulation requires certain attributes to be met with respect to sustainability. However, more sustainable choices have to be seen as good value (from the broadest perspective, not just financial) to be given adequate legitimacy to be incorporated in the final built form.

Whilst the definitions are unclear, there is general support that sustainability requires stakeholder participation. Additionally, due to the many facets of sustainable development there is also agreement that it is very difficult to implement therefore, the challenge is to find ways to implement the concept into everyday life. This research will look at opportunities to implement sustainability through the design process, with a particular focus on the design of buildings and selection of roof components. It will investigate ways of defining sustainability within a particular project context, so that a way of assessing options and informing decisions can be developed through corroborated performance (scientific approach) and stakeholder engagement (normative approach). In the case of this research the ultimate decisions will be focused around the roof.

The literature review identified some emerging pragmatic realist techniques that endeavour to integrate scientific principles of sustainability with the stakeholder participation. Such approaches include The Natural Step's Backcasting Approach (Holmberg, 1998, Holmberg and Robèrt, 2000) and DesignWays (Tippett, 2005, Tippett et al., 2007). Both of which take a strong sustainability stance, basing their fundamental reasoning on ecological principles. Whilst this is an area identified for future research, the focus of this research will not be on developing these further and the progression of an approach to sustainable roof selection will be based on delivering shorter term benefits in the industrial context and selecting better roofs in relation to the client's social, environmental and economic objectives. It will not challenge the current economic paradigm that is prevalent with many of the clients that the sponsoring organisation currently works with. Instead the stance is based on a weak sustainability perspective. This will look to develop an approach for decision making which allows the stakeholders to understand what gives the most value, in environmental, economic and social considerations, when weighting these aspects as they see the most important. It was considered taking a strong sustainability stance in the context of the industrial work with the sponsoring organisation would be unfeasible.

The review considered building environmental assessment methods which are typically used for defining sustainability in the project context and the advantages and limitations of these approaches. Undoubtedly, such methods have had a positive influence on the industry, raising awareness of environmental issues in the design and construction of buildings. So much so that there are a multitude of assessment methods that are currently in use around the world. However, there are also some limitations and many authors are now arguing that their role is changing. Some of the limitations are as follows:

- The inability to acknowledge regionally specific environmental criteria.

- Not being designed to inform design but used to assess design. There is no accompanying decision making process.
- Weightings are not made explicit.
- Lack of ability to offer different levels of assessment output (i.e. less detailed at the earlier design stages , when information is limited).
- Inability to incorporate stakeholder requirements.

This research aims to define techniques that will start to account for some of these limitations and in doing so help address the research question and objective outlined above. Subsequent areas to progress as outlined in the literature review include:

- Integration of environmental, social, economic and technical aspects, as many assessment systems tend to overly focus on environmental considerations.
- Integrate stakeholder values, needs and preferences into the design, delivery and operation of the built environment and provide relevant information and key decision points.
- Integrate stakeholder knowledge, rather than considering purely expert knowledge
- Improve transparency and accessibility.
- Provide access to relevant information on which decisions can be made.
- Communicate the information and results in easy to understand ways for stakeholders.
- Provide opportunities for collaborative learning and the transfer of knowledge.

Collectively these two lists, as summarised from the literature, provide a good starting point from which to develop an approach to defining sustainability in the project context, which this research will seek to do.

The concepts of value and sustainability were then reviewed in parallel to consider the relationships between the two concepts. Both concepts are argued to be value laden. Additionally, they both require stakeholder input. Furthermore, value is an important consideration by stakeholders on a project and if they feel that a design or system is not giving them value, then it is unlikely to be delivered on a project. Therefore, this author argues that if sustainability features are not required by regulation, then they will have to be seen as good value by stakeholder groups of the project, and those paying for the project in order to be constructed in reality. Additionally, some of the techniques for understanding value could also potentially be used in the sustainability context and this should be considered through further research. These include techniques such as the Design Quality Indicator (DQI) (Cole-Colander, 2003, Gann et al., 2003) and the Value in Design (VALiD) approach (Austin et al., 2005b). Testing such approaches in this context will better understand their appropriateness for application at the start of design and understanding stakeholder values.

The literature reviewed considered the challenges of the design process. This was considered important to ensure that any approaches used or developed to understand sustainability better in the project context should seek to work within these constraints. The main challenges that emerged are listed in the summary for section 2.3.3:

2.5 Conclusion

This part of the literature review has considered the history, concepts and definitions of sustainability and how sustainability is typically considered in the building industry. This has reviewed building environmental assessment methods and identified the current limitations in their approaches. Other aspects have also been reviewed such as value in the building industry and the challenges of the design process. The development of decision support techniques, will require consideration of these inter-related concepts. Then the section is summarised and the research gaps identified. The particular research gaps that this work will focus on are as follows:

- The lack of stakeholder driven approaches to defining sustainability for a building's context
- The insufficient exploration of methods for integrating environmental, social and economic value
- The need for approaches that address the challenges of the design process.

These are the main areas of this chapter of the literature review that have informed the development of the research questions in section 5.2.

The next section reviews the literature with respect to sustainable roof selection.

3 Literature review: sustainable roof selection

3.1 Introduction

The first part of the literature review looked at definitions of sustainability, different approaches to practice and the current approaches to sustainable building design in the construction industry. This part of the literature review focuses in more detail at roof design and selection. This review begins by considering the definition and function of a roof and considers why the roof is important from a sustainability perspective. A brief history of roofs is given and explored, and how the need has arisen for improved methods of selecting between roof options to reflect current sustainability issues. The review then covers a variety of roof systems that are generally discussed in the literature for their sustainability credentials, and also reviews some commonly used environmental assessment methods to define typical objectives for consideration in sustainable roof selection.

Then previous work in the field of roof selection and decision making is reviewed. The objective of this is that the work undertaken in this thesis builds on the knowledge gained through previous work and also bridges some of the gaps in knowledge. The literature review is concluded by summarising these areas of further work and this has been used as a starting point for the original work presented in this part of the thesis.

3.2 What is a roof and why is it important?

There are many different definitions for a roof. One such definition is as follows, the *“top surface of a building that provides a weather-proof barrier for the building interior”* (Kosareo and Ries, 2007). Other definitions include, *“the upper portion of the building envelope that is horizontal or tilted at an angle of less than 60° from horizontal.”* (Abu Dhabi Urban Planning Council, 2010). Harrison et al. (2009) are more specific with their definition, defining a roof as, *“the upper structure for and covering of a building.”* They define, *“roofing as the materials that form the covering.”* Roofs are difficult to tightly define and this is partially reflected in the numerous definitions of what they are. Additionally, roofs are often unique in their construction and there is no such thing as a standard roof as so many different combinations are possible (Brotruck, 2007). Therefore, before continuing it is worth noting that whole books have been written covering different roof types (Coates, 1993a, Wickersham, 1987, Harrison et al., 2009).

However, when considering the question, ‘what is a roof?’ it is important to consider the roof’s relationship with the building and the higher level functions and purposes of buildings in society. These are wide ranging and extremely complex and inter-related. They include symbolic, practical, financial, aesthetic benefits and occasionally problems. However, a key requirement is that buildings provide shelter and security. The dominant element which helps achieve this function is usually the roof (CIRIA, 2003). The roof satisfies a fundamental human need – it protects us from rain, wind and cold (Brotruck, 2007). Therefore, the roof is of paramount importance in satisfying a physiological need, which is stage one in Maslow’s Hierarchy of needs (Maslow, 1943). The roof is particularly important in this respect because it has the highest exposure to the sun of any of the building facades (Berdahl et al., 2008). It is also often a significant proportion of the building envelope and consequently it is a major surface for heat transfer and water runoff, increasing the building’s energy requirements and runoff contribution (Berdahl et al., 2008). Consequently, roofs contribute significantly to the environmental problems and therefore their improvement offers significant potential in reducing these impacts.

Harrison et al. (2009) also list the following basic functions of roofs:

- Strength and stability
- Dimensional stability
- Exclusion and disposal of rain and snow
- Energy conservation and ventilation
- Control of solar heat and air temperature
- Fire safety and precautions and lightning protection
- Daylighting and control of glare
- Sound insulation
- Durability, ease of maintenance and whole-life costs

Some authors state that the function of the roof is *‘to protect the building from environmental factors such as light, wind, rain, snow loads, temperature changes, hail, and storms’* (Ramachandran et al., 2002). Other authors state that the primary function of the roof is *‘to protect the underlying structure from the weather for a long period of time, at a low cost’* (Berdahl and Bretz, 1997). The researcher believes that including the design life of the roof and the cost in the function of the roof makes the function too specific to be used in all situations. For example, in the case of a temporary structure, the building may reasonably have a short design thus rendering the above definition of the roof’s function inappropriate.

However, this author believes that considering the roof function, abstract from the function of the building is ignoring the inter-relationships between the two systems and the larger scale function and the impacts, of both the roof and the building, on society. Therefore, it is the opinion of the author that one must consider more than the immediate protective element when considering roof selection. Wickersham (1987) states that, *“roofing [is] a marriage of beauty and function. The dome of St Paul’s was designed to do rather more than keep out the rain. This truism may be applied to any roof irrespective of the building it covers. Whether it is the crowning glory of a Wren cathedral, or just the lid over one’s humble home, its requirements remain very similar. At first sight it should be to please the eye; but to be deemed a success, it must fulfil several functional objectives.”*

Yannas, Ereel et al. (2006) state that the mainstream approach to roof design has emphasised the roof’s protective function (as Coates (1993a) focuses upon). Although the protective function is almost always necessary, protective mechanisms are not sufficient in themselves to make a building independent from conventional heating and cooling. Their book investigates ways in which the roof can be used as an energy sink to dissipate excess heat as well as renewable resource for space heating. Renewable energy sources that are available to the building are sunshine and heat from occupants of the building. Roofs are generally the most exposed element of a building’s external envelop and thus have a large part to play (CIRIA, 2003). Yannas, Erell et al. (2006) highlight that the balance between the protective and selective environmental functions of the roof is a temporal function as well as a contextual parameter. Main subject areas they cover include roof ponds, cooling radiators and green roofs. This has more applicability in hot climates, whereas in cooler climates, building cooling may only be appropriate for a small proportion of the year or not at all.

Additionally, other authors also elaborate on the potential of the roof. The world renowned architect Norman Foster states the following, *“I hold no personal brief for flat roofs against pitched roofs. There are no easy generalisations - they are each that fifth and important elevation. Looking down from any high-rise building in a city I am struck by the way we squander this fifth elevation. All too often it becomes an engineers' battleground -the last left-over space where the detritus of air conditioning finally takes root. Consider the lost opportunities to recreate those valuable site footprints in the sky as gardens for people or more prosaically consider the scope for roofs which are perforated for natural light - to discover its dimension of poetry as well as its potential for saving energy. With new and discreet ways of environmentally servicing buildings, the roof can revert to letting in the sun and keeping out the rain” (CIRIA, 2003).*

Other's express the importance of the roof. Graham Bateman in the introduction of Coates (1993a) states that, *"The contribution made by the roof in the putting together of any building project is all-embracing, and it is largely under-valued. The roof is vital to the purpose demanded of all buildings, i.e. their exterior and interior well-being. It can do much as a medium for the designer's aesthetic and technical skills, and for all this, although it can be the subject of merciless economies, it is rarely an element of major consequence in the overall compilation of costs."*

Unfortunately, roofs are often overlooked as space that can be designed into an environmental amenity for buildings. If the roof surface can be transformed into useful space, the building becomes economically and functionally more efficient and can have a more benign effect on the surrounding landscape (Carter and Keeler, 2008). Roofs can reduce environmental impacts of buildings and even improve the biodiversity of the site by providing habitat replacement (Newton et al., 2007). Therefore, well designed roofs present the possibility of not only being 'benign' to the environment, but actually providing positive environmental, social and economic benefits. It is for this reason that improved roof design and selection offers a high leverage solution in developing a more sustainable future.

3.3 Historical roof design, selection and construction

The history of roof construction is covered in numerous texts (Coates, 1993a, CIRIA, 2003, Harrison et al., 2009). A brief summary is given in this section to provide the reader with this context and to establish why the need for a roof decision making tool has arisen.

Traditionally roofs were constructed out of local materials with techniques that responded to the demand of the local climate and user customs. Before the industrial revolution, the transportation of materials and skills was inefficient and thus local labour, materials and techniques prevailed. Even today in many parts of the world unique regional roofing practices survive because they continue to be cost effective and meet user needs (Kyle et al., 2000). Essentially, in the past, roof type would have been selected according to two things, the local climate and the availability of local materials. Sir Norman Foster in the introduction to the book, "Flat Roofing Design and Good Practice" (CIRIA, 2003) explains that when he was undertaking a planning strategy for Gomera, a small island in the Canaries, he was, *"fascinated to discover that the indigenous buildings were of two distinct types, depending on where you were relative to the mountains which rose dramatically out of the centre of the island. The prevailing wind created a rain shadow over one side of the island and the buildings responded with pitched roofs covered with tiles. On the other side, which was noticeably warmer and drier, the structures were essentially flat-roofed. The platforms that they created were often shaded and used as outdoor rooms..."* This reflects the influence of climate on the roof choice. He goes on, *"The thatched cottage may appear quaint and rustic today, but in its heyday it was an advanced technology which used available materials in the most efficient and effective way possible. The true vernacular was always generated by the needs of people, the constraints of climate and the economy of means. Those buildings in Gomera were rooted in such realities; the existence of flat and pitched roofs on opposite sides of the island did not arise out of fashionable whim."*

Additionally, it could be argued that the choice of which roof system to implement was much simpler than it is today. There were less options (the decision was constrained by what materials were locally available), modern methods of construction were not yet developed meaning that the roof construction was also constrained by the local knowledge of what works and the experience of the local work force.

However, with the development of infrastructure and transportation methods, moving large volumes of heavy materials was made considerably easier. Materials can now be readily transported across countries and even exported to other areas of the world. Consequently, imported materials coupled with globalised modern methods of construction now compete directly with traditional and local techniques and materials (Coates, 1993a). This is again reflected by Foster, who states that, *"Today the materials and technologies of mass production and distribution are becoming universal to the extent that the true vernacular for certain building types is often the economical metal box. Sadly the all-too-familiar metal box has become the building equivalent of fast food - a convenient short cut, but often divorced from contact with the place, its climate and any social or cultural connections. Without denying the growth of a global market for building products, these can, like any materials from an earlier tradition, be used with a sensitivity to the site and its context."* (CIRIA, 2003).

At the same time as the industrial revolution has enabled the relatively cheap and easy movement of materials, roof forms have evolved with the development of structural methods for spanning space – post and beam, arches, domes, vaults, trussed, slabs, wrapped membranes, etc. The development of a wide variety of flat roofing systems for many different types of building has been driven in part by the evolution in the C19th, of metal and concrete framing systems capable of spanning large distances without the 'space hungry' geometry of arches, domes, etc. The development of materials including lightweight products such as corrugated roofing, made of asbestos or fibre glass, coupled with improved structural performance meant that roofs could span larger distances (Coates, 1993a), with longer spans, flatter roof pitches were required to ensure that the roofs didn't get unfeasibly high.

Flat roofs have numerous definitions, however for the purposes of this research, we shall use the following definition of a slope of less than 10° (Harrison et al., 2009, CIRIA, 2003).

Flat roofs can be constructed to support people, vehicles and vegetation. Thus a flat roof can be used as a terrace, car park or for fitting the plant of the building. They started to become popular during the 1960s and 1970s as there was a trend towards the design of flat roofed buildings (Coates, 1993a). They have historically developed due to their benefits which include (CIRIA, 2003):

- minimising the enclosed volume
- maximising the planning envelope in volume terms
- frees the plan to allow variations in shape
- simplifies the structure

- provides access to the roof as a ‘floor’ for people , equipment, landscaping
- optimises the dimensions of the ‘roof zone’
- in the case of continuous membranes, allows the building to be ‘sealed’ against air, dust and noise infiltration (but with concomitant condensation problems)
- allows economies of scale for large plan buildings arising from large sheet materials, repetition and/or prefabricated details, etc.

The development of new products also meant that the flat roof movement gained significant attention. There was a swing in architectural fashion away from pitched roofs and towards flat roofs. This was partly influenced by the Bauhaus movement in the 1920s (Harrison et al., 2009). Other influencers at the time were French-Swiss Architect Le Corbusier who introduced the idea of the roof as the fifth facade. This had an important influence of 20th Century architecture and roofing (CIRIA, 2003). Additionally in the periods following the World Wars there was significant development and building and construction work on an unprecedented scale. From 1950-70 there were therefore a mixture of successes and failures and often on a large scale. The multi-layered felt roofing was frequently specified for roofs with virtually no fall, and with a multitude of openings. During this period many unsatisfactory flat roofs were built due partly to poor materials, workmanship and detailing. The poor reputation of felt roofing was difficult to shake off. However, better membranes were developed and fixing methods improved. Now flat roofs are as durable as other types of industrial roofing

Until the 1970s little regard had been given to what functions the roof could provide other than primitive protection. Until this point most buildings were constructed without thermal insulation as the concept of energy efficiency was not taken seriously (Coates, 1993b). However, during the 1960s and early 1970s, several events majorly influenced the roofing industry. Industrial action, by coal miners and power supply workers in addition to the escalation of oil prices caused large increases in the price of energy (Mahdjuri, 1994). Of particular note was the oil crisis of 1973. The immediate result was that building owners found that their heating costs were ‘going through the roof’ (Coates, 1993a). This prompted the response of investigating improved thermal performance (especially from roofs) (CIRIA, 2003).

Over time building regulations in the UK became more stringent, requiring greater performance from the roof in terms of increased levels of thermal performance. This was often provided with increased thicknesses and performance of insulation. This has driven roof design and selection through the enforcement of mandatory regulations. However, these only focus on some areas, such as thermal performance and the selection of materials that are not hazardous to health. Recently there has been increased focus on other areas that roofs influence, such as their embodied impact through the extraction, processing and use of materials (Anderson et al., 2009).

Very recently some authors are starting to consider the explicit importance that roofs can have. Scherba et al. (2011) state that rooftops are playing an increasingly important role in urban sustainability efforts. Additionally, there has also been some limited focus on how to improve the selection of roofs to improve the sustainability of buildings and the built environment (Section 3.7).

3.4 The impact of roofs on the environmental assessment methods

The roof impacts on many environmental assessment methods. Whilst EAMs are typically not compulsory, many local authorities in the UK and best practice Clients are now aspiring to achieve certain levels of performance through achieving certain categories of performance when assessed under the respective EAM for the region.

Environmental assessment methods are introduced in Section 2.3.1, so their purpose and structure is not covered in more depth here. Instead, this section reviews three international building environmental assessment methods and identifies credits relevant to roofs. This expands on work undertaken by Grant (2007) who just considered LEED. Environmental assessment methods are also a major driver in the case of many projects, so it is important that a roof selection tool has the capability to align with environmental assessment methods. Whilst there are a large number of EAMs worldwide the following three have been selected. BREEAM because it was the first EAM to be introduced, and has been the basis for the development of many other EAMs. LEED because it also receives significant attention and is often used on projects in the USA and also internationally around the world. Estidama was selected because it is a younger assessment method, developed partly by the sponsoring organisation and also because it was developed for use in Abu Dhabi, which has a hot arid climate type (Koppen Geiger classification of BWh) and thus is significantly different from the UK’s climate type, and the majority of the USA.

Table 3—1 shows the most relevant roof considerations as identified from a review of the different EAMs.

Table 3—1 Roof related criteria for BREEAM, LEED and Estidama environmental assessment methodologies

BREEAM (BRE, 2011)	LEED (US Green Building Council, 2009)	Estidama (Abu Dhabi Urban Planning Council, 2010)
MAN05 Life cycle cost and service life planning HEA05 Acoustic Performance MAT01 Materials ENE01 Reduction of CO_2 emissions ENE04 Low and Zero Carbon Technologies POL03 Surface Water Runoff LE03 Mitigating Ecological Impact LE04 Enhancing Site Ecology MAT03 Responsible Sourcing of Materials MAT04 Insulation WST01 Construction Waste Management	SS5.1 Protect or Restore Habitat SS5.2 Maximise Open Space SS6.1 Stormwater Design – Quantity Control SS6.2 Storm Water Design – Quality Control SS7.2 Heat Island Effect - Roof	LBO-R3 Outdoor Thermal Comfort Strategy LBO-1 Improved Outdoor Thermal Comfort PW-2.1 Exterior Water Use Reduction RE-2 Cool Building Strategies SM-2 Design for materials reduction SM-4 Design for disassembly SM-6 Design for durability SM-11 Rapidly Renewable Materials

Roofs have a significant impact on the above environmental assessment methods. With respect to BREEAM, a review shows that over 27 credits are influenced by roof selection. This represents up to 22% of the overall BREEAM score. With respect to LEED, 22 points are influenced by the roof selection out of a potential 100. Finally, for Estidama, 29 credits out of a possible 177 are influenced by roof selection, representing up to 16% of the overall score.

For more information, on how each criteria relates to the roof system and how this is quantitatively assessed, please see Appendix P. For each list, the number of points available for each credit is listed and a brief explanation given as to how this relates to the different roof options for a project is described. Additionally, how these points are assessed or awarded is also detailed. This will form an aspect of the roof decision support system, as environmental assessment methods are often considered strong drivers for projects. The manuals for each assessment systems are typically significant documents consisting of hundreds of pages. In the first instance, the documents were searched for the word roof, before a more comprehensive review was undertaken.

3.5 Defining a sustainable roof

From a rationalist, positivistic viewpoint, it would be beneficial to be able to globally define what a sustainable roof is. If this was defined then a method of measuring a roof's sustainability against this definition would be possible. In essence the sustainability of a particular system would be able to be documented and the sustainability of a roof would be able to be compared quickly and easily and also benchmarked against other roof types. This has received a limited amount of attention for flat roofs.

Hutchinson (2001) states that the best working definition of sustainable roofs is *"A roofing system that is designed, constructed, maintained, rehabilitated, and demolished with an emphasis throughout its life cycle on using natural resources efficiently and preserving the global environment."*

However, even Hutchinson (2001) states that the definition is difficult to comprehend and also very difficult to implement in practice. This author would also argue that the definition is incomplete as it only takes into account environmental sustainability, and discounts social and economic factors.

Hutchinson and Roberts (2001a) compiled the following tenets of sustainable roofing in collaboration with a task group of recognised experts and roofing specialists from more than 20 countries. The purpose of this list was to offer practical advice for the roofing industry in order to deliver sustainable roofing systems. A justification of each tenets inclusion is outlined in Hutchinson and Roberts (2001a). The 21 tenets are included below.

"Minimise the burden on the environment

1. *Use products made from raw materials whose extraction is least damaging to the environment.*
2. *Adopt systems and working practices that minimise wastage.*
3. *Avoid products that result in hazardous waste.*
4. *Recognise regional climatic and geographical factors.*
5. *Where logical, use products that could be reused or recycled.*
6. *Promote the use of green roofs supporting vegetation, especially on city centre roofs.*
7. *Consider roof designs that ease the sorting and salvage of materials at the end of the life of the roof.*

Conserve energy

8. *Optimise the real thermal performance, recognising that thermal insulation can greatly reduce heating or cooling costs over the lifetime of a building.*
9. *Keep insulation dry, to maintain thermal performance and durability of the roof.*

10. *Use local labour, materials and services wherever practical to reduce transportation.*
11. *Recognise that embodied energy values are a useful measure for comparing alternative constructions.*
12. *Consider the roof surface colour and texture with regard to climate and the effect on energy and roof system performance.*

Extend roof lifespan

13. *Employ designers, suppliers, contractors, trades people and facility managers who are adequately trained and have appropriate skills.*
14. *Adopt a responsible approach to design, recognising the value of the robust and durable roof.*
15. *Recognise the importance of a properly supported structure.*
16. *Provide effective drainage to avoid ponding.*
17. *Minimise the number of penetrations through the roof.*
18. *Ensure that high maintenance items are accessible for repair or replacement.*
19. *Monitor roofing works in progress and take corrective action as necessary.*
20. *Control access onto completed roofs to reduce puncture and other damage, providing defined walkways and temporary protection.*
21. *Adopt preventative maintenance, with periodic inspections and timely repairs.*

Notes

1. *These tenets are applicable to membrane roofing systems on permanent buildings.*
2. *As our understanding develops of how roofs perform and how they affect the global environment, then the tenets will also evolve."*

A critical review of some of the above tenets is given below.

This author believes that the above provide some useful guidelines, they are not a comprehensive list and also do not account for trade-offs between different issues. Additionally, they have not been explicitly reviewed through the environmental, economic and social lenses of sustainability.

The tenets ignore, to some extent, the resources that are available at the roof level for use in the building. For example, with respect to “conserve energy”, which is a key area under which five of the tenets of sustainable roofing fall, there is not consideration of the roof’s availability as a space to house renewable technologies and therefore produce energy. Additionally, this may or may not be important. For example, the performance requirements of a bus shelter and its associated impact differ significantly from that of an office. Therefore, what is defined as a sustainable roof requires consideration in line with the function required and the needs and expectations of the users of that roof/building. This may have been excluded due to the focus on membrane roofing systems and less on the broader functions roofs can provide.

With respect to resources such as water, the tenets do not consider water incident on the roof, and the impact of this flow on the built environment. Whilst typically in an urban environment runoff from roofs enters storm water systems and often contributes to peak surges, which can in some situations cause flooding. The only mention of water at roof level is tenet *16 – provide effective drainage to avoid ponding*. This author recognises the possible adverse impacts of leaking roofs caused by roof ponding. However, the design of roofs to shed water as quickly as possible to avoid ponding can be a contributing factor to localised flooding and thus could be argued is a tenet that is unsustainable in some contexts. Recent literature, has explored the possibility of inducing roof ponding and storage of water at roof level to increase the lag time of runoff and decrease peak flows in the built environment (Harrop, 2010). These reflect the modern performance of roof systems, which have improved significantly over recent years. This has led to the reduced occurrence of leaks. Now designers in some situations are actively reducing the number of down pipes on the roof and inducing ponding. This is termed by Harrop (2010) as a “blue roof” and has the benefit of discharging rainfall runoff over a longer period easing the peak flow impact on drainage infrastructure. Other benefits shown by the Harrop (2010) case study include a significant reduction in the roof costs, but also reduced requirement for the underground storage of rainwater (and the associated costs) which would have been required without the use of a blue roof.

The principles as outlined by Hutchinson (2001) and Hutchinson and Roberts (2001b) whilst providing a checklist suitable for some considerations, does not consider the context of the project in any explicit way. With perhaps the exception of tenet 6 “Promote the use of green roofs supporting vegetation, especially on city centre roofs”, which considers the urban context at a high level.

It also fails to offer a way of prioritising. For example, is durability more important than costs? The roof is considered on the whole as an isolated system with the exception of some elements of ‘conserve energy’, which presumably refers to building energy consumption. The interactions between the roof and the building that it shelters and the function that building provides are not considered in depth. The tenets focus narrowly on what appears to be material and product selection. The roof could potentially help achieve many project specific requirements. These may include the provision of external green amenity space or solar energy; the roof may be the only location for this in the urban environment. Additionally, cost is also an important consideration, which is not included in the list. How to deal with the trade-off between improved performance in the tenets and the potential increase in costs is not considered in their work.

There is no explicit prioritisation of these issues and there is no attempt, other than providing a checklist, to influence decision making. It is accepted that a comprehensive list of principles for sustainable roof selection would be impossible to define from a positivistic viewpoint. What constitutes the most sustainable roof from a holistic perspective is very hard to define. Defining what is sustainable is highly context specific, and this is no different when considering roofs. Selecting which roof is more sustainable for a particular building function in a hot climate, will require a different set of criteria, with different priorities and influences to a roof for a building with a different function in a cool climate. Therefore, the decision making framework needs to be able to be adaptable to consider aspects relevant for the project in question. These aspects will then be defined as the decision making criteria.

Whilst, some aspects are likely to be highly context specific and the decision making framework is likely to require flexibility to account for such issues, the performance of roof systems in some areas is likely to be often of interest. To define these areas a review of the impacts of roofs on various elements of the performance of buildings has been conducted. This research does not aim to define the weightings on the particular elements of performance but instead aims to develop an approach and decision making tool to be able to rapidly assess different roof options with respect to some attributes of performance and their weightings. This will require explicit consideration of the impact of various roof systems on some elements of performance. To guide the selection of these, a review of the aspects of roof performance that are typically discussed in the literature is considered, along with how the different aspects of performance can be quantified.

3.6 Roof system types

This research is focused on developing an approach to roof selection for building projects which helps achieve the environmental, economic and social objectives of the project. This will involve selecting between a number of roof options or systems. The next sections consider the sustainability implications of different types of flat roof systems which may form part of the selection process. Whilst a comprehensive review of all different roof types is beyond the scope of this research a range of roof types have been considered. These have been categorised into either traditional roofs, green roofs, cool roofs, solar technologies, rain water harvesting and are discussed in the following sections.

3.6.1 Traditional roofs

Traditional roofs are defined for the purposes of the research as roofs which are widely used and their performance is relatively well understood. These are not reviewed significantly in this work, as they are well covered elsewhere. However, many of the products outlined in Section 2.5, such as Built-Up Roofing, Coatings, Metals, Modified Bitumen, etc. would normally be classed as traditional roof types, providing a water proof barrier against the elements. These have all been included in the prototype roof decision support tool, as alternatives that can be compared. However, it should be noted that due to their impermeable characteristic and their runoff attributes not varying significantly, the main differences will be judged on cost, their ability to minimise temperature extremes through their albedo and emissivity, and their life span. They are primarily included to provide a benchmark against which roof systems such as green roofs (intensive and extensive), cool(er) roofs and the installation of renewable technologies, and the requirements of rainwater harvesting systems can be compared against.

Whilst in depth descriptions of numerous roof types can be found in books such as Harrison et al. (2009), this thesis is looking at the roof system from the water proof layer up. The exact configuration of the different roof types, such as whether to select a “cold roof deck” layout or a “warm roof deck” layout is not considered in great depth.

CIRIA (2003) explains a design selection process for typical roofing types. This guide states that, *"the process design selection for a complete roof relies on a series of interacting decisions. It is possible to address the questions involved in varying orders and from different starting points."* They include a flow diagram of the considerations required when selecting different roof types. However, no decision making aid is provided to quantify and assess the different roof options. Additionally, they focuses on the design issues relevant to both the material workmanship and details approaches through the design process relevant to the performance specifications. They place no particular emphasis on the environmental performance on what the roof can offer the building from a social and economic perspective. The focus is more on correct specification than the selection of holistic roof systems.

Whilst roof products are vast and a comprehensive review of all types of roof is not possible, there are some standard roof types which form the outer 'skin' of the roof that are briefly explained in this section. These are as follows (Energy Star, 2013):

- ***Built-Up-Roof (BUR):*** *Traditional hot asphalt or coal tar built-up roofing membrane assembly consists of alternating layers of felts, fabrics, or mats saturated with bitumen during manufacture, assembled in place, and adhered with applied layers of hot bitumen. Surfacing for the hot BUR can be aggregate embedded in hot asphalt; mineral-surface cap sheets; modified bitumen cap sheets; or smooth-surface applications or coatings.*
- ***Coating:*** *A material typically applied in the liquid state to the roof surface at the time of construction or at a later time as a retrofit measure. Roof coatings may be bituminous, polymeric, polymer modified, epoxy based, or other formulations. Bituminous roof coatings are formulated using bitumen. Polymeric roof coatings are formulated using a variety of synthetic resins such as acrylic, neoprene, styrene butadiene, urethane, polyvinyl acetate, and others. Polymer modified roof coatings are manufactured by combining a portion of the polymeric technology with bitumen technology.*
- ***Metal:*** *Steel and aluminium sheets are commonly used to fabricate metal roof panels. Steel requires a corrosion resistant metal coating such as zinc, aluminium, alloys of zinc-aluminium, or tin. Metallic coated steel includes galvanized steel, aluminized steel, zinc-aluminium-coated steel and terne-coated steel. Metallic coated steels may also be painted to provide additional corrosion protection, as well as colour.*
- ***Modified Bitumen:*** *Roll roofing products consisting of asphalt, reinforcing layers, and in some cases, surfacing.*

- ***Shingle:*** *Composed of a base material, either organic felt or glass fibre mat; asphalt; and surfacing material, generally in the form of mineral granules.*
- ***Single-Ply Membrane:*** *A term applied to a sheet membrane which is a membrane fabricated in a controlled factory environment. It is waterproof and weather resistant. It may be a laminate of one or more materials and may or may not contain reinforcing fabrics.*
- ***Spray Polyurethane Foam Roof System:*** *A fully adhered system that consists of a rigid closed-cell sprayed-in-place polyurethane foam insulation and a protective roof coating. Typical coatings include acrylic, silicone, or urethane elastomers.*
- ***Tile:*** *May be composed of clay, concrete, fibre-cement, or synthetic materials. A variety of tile profiles, styles, finishes, and colours are available.*

The above roof types have not been reviewed in much depth as they are considered relatively well understood and covered elsewhere. Information on the performance of such types of roofs is significant and databases covering many aspects of their performance already exist (Anderson et al., 2009)

There are a number of roof types and roof systems that are growing in prominence and are generally considered to have improved environmental credentials. These are briefly discussed in the respective sections below, as such systems are likely to be those which will be considered for building projects and thus form the options between which a decision on the type of roof system to select will have to be made.

Each roof type is defined in their respective section and for each roof type a brief overview is given on how they impact on various environmental, social and economic issues. A more complete literature review on their performance implications for each is given in respective appendices. These have been critiqued and will help form ways of assessing the performance of different roof systems within the prototype roof decisions support tool.

For some roof types, there are many more performance elements to assess, for example green roofs. Additionally, the performance of such roofs is significantly more complex and research in these areas is rapidly advancing. For these reasons, the section on green roofs is longer and further accompanied with a further description in Section 3.6.2 and further description in Appendix L.

Different roof types have been reviewed primarily from a performance in use perspective rather than their impact in production. However, some focus is given to material selection and the impacts of production. This reflects the general in-use impacts being far greater than those in production, with the exception of products with a very short lifespan.

3.6.2 Green roofs

Green roofs are roofs that are purposely fitted or cultivated with vegetation. They can also be known as living roofs, eco-roofs or vegetated roofs (CIBSE, 2007). It is generally accepted that there are two main types of green roof which are described by Kibert (2008) as:

- *“Extensive: Extensive landscaped roofs are defined as low maintenance, drought-tolerant, self-seeding vegetated roof covers that incorporate colourful sedums, grasses, mosses, and meadow flowers that require little or no irrigation, fertilisation, or maintenance… Extensive systems can be placed on low-slope and pitched roofs with up to a 40% slope.*
- *Intensive: If there is adequate load-bearing capacity, it is possible to create actual roof gardens on many buildings. This type of eco-roof system may include lawns, meadows, bushes, trees, ponds, and terraced surfaces. Intensive systems are far more complex and heavy than extensive eco-roof systems and hence require far more maintenance.”*

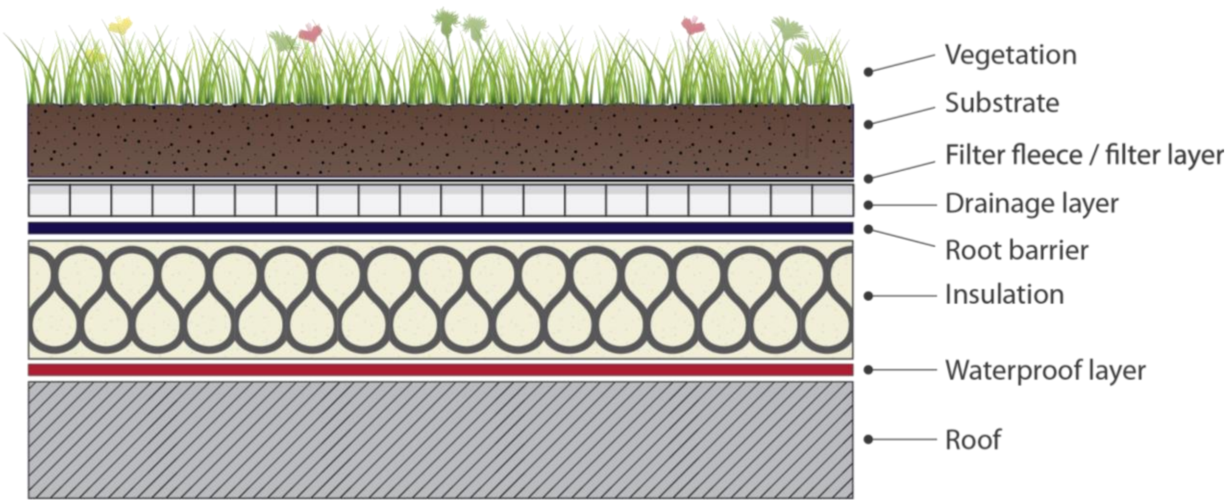


Figure 3—1 Cross section through a typical green roof

Extensive green roofs are the most popularly deployed forms of green roofs as they are generally light weight and low cost. Some authors also describe a third type of green roof as simple intensive which usually comprises of grasses, herbaceous plants and shrubs. Simple intensive can be constructed using varying depths of substrate, thus combining elements of extensive and intensive roofs (Newton et al., 2007). Further classification has been undertaken by the FLL, which comprise of the German Green Roof Standards. They classify roofs into eight types which are detailed in Table 3—2. These are the eight types of green roof that are considered in Grant (2007) decision making framework for green roofs.

Table 3—2 Green roof types, depths and forms of vegetation (Grant, 2007, FLL, 2002)

Type of greening	System Type	Course depth (cm)	Form of vegetation
Extensive greening	1	02-04	Moss-Sedum
	2	04-06	Sedum-moss greening
	3	06-10	Sedum-moss-herbaceous plants
	4	10-15	Sedum-herbaceous-grass plants
	5	15-20	Grass-herbaceous plants
Intensive greening	6	15-25	Lawn, shrubs, coppices
	7	25-50	Lawn, shrubs, coppices
	8	>50	Lawn, shrubs, coppices, trees

Historically they were common in the UK and Northern Europe, but became less common as the industrial revolution progressed. However, presently green roofs are increasing in popularity in many countries due to their numerous advantages (Emilsson and Rolf, 2005). Germany is leading the current drive in green roofs where now 10% of all German roofs have been greened, 80% of which are extensive sedum roofs (CIBSE, 2007). The Swiss are also pioneering the use of green roofs with 70% of flat roofed inner city buildings having roof gardens (Yuen and Nyuk Hien, 2005). Spala, Bagiorgas et al. (2008) argue that the installation of green roofs is well established in the USA, Japan and in Europe, with Germany and Sweden being particular leaders.

Green roofs have recently received substantial attention in both popular media and also academic research. This research reviewed a large number of green roof papers primarily from peer reviewed academic journals.

However, whilst the performance of green roofs is a rapidly growing research area, it should be noted that some countries now have their own guidance and codes for the installation of green roofs. The first set of guidance was the German Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) (FLL, 2002). Work started on this in 1982 and has been regularly updated and refined ever since (Waldbaum, undated). The FLL has usefully been translated into English. Other countries including Austria and Switzerland also have green roof standards, however these are only available in German. A comparison of the three codes has been undertaken and the German FLL is considered the most comprehensive and is considerably referenced in both the Austrian and Swiss standards (Waldbaum, undated). The UK has also recently developed its own standard for the UK context (Green Roof Organisation, 2011). Whilst these deal with the specification of green roof systems, none of them explore how to select the best roof system.

Research on the performance of green roofs has advanced rapidly over recent years with much research documenting their diverse benefits which include:

- Sustainable Drainage
    - Retention of Water (VanWoert et al., 2005)
    - Detention of Water (Carter and Rasmussen, 2006, CIRIA, 2007, Hilten et al., 2008)
    - Water quality (Berndtsson et al., 2006)
- Energy (Sailor, 2008, Lin and Lin, 2011, Niachou et al., 2001, Castleton et al., 2010)
- Urban Heat Island Effect (Alexandri and Jones, 2008, Scherba et al., 2011)
- Local Biodiversity (Köhler and Poll, 2010, Brenneisen, 2006, Dunnett et al., 2008b, Schrader and Böning, 2006, Newton et al., 2007)
- Durability and lifespan (Bjork, 2004)
- Air quality (Yang et al., 2008)
- Amenity Space (Greater London Authority, 2008, City of London Corporation, 2011)
- Acoustic performance (Van Renterghem and Botteldooren, 2008, Van Renterghem and Botteldooren, 2009)
- Visual amenity / Aesthetics (White and Gatersleben, 2011, Yuen and Nyuk Hien, 2005);
- Whole life costs (Wong et al., 2003c, Carter and Keeler, 2008, Clark et al., 2008),

With the growth in green roof research there is now a significant amount of quantifiable data. This could potentially be used to justify the inclusion of green roofs on projects. For a more detailed review of green roof performance, please see Section 12 and Appendix L. The section in the appendix explains some of the research in the above areas of green roof performance, details some of the key variables that affect the performance in these areas, and also where appropriate highlights some of the methods of quantifying these elements of green roof performance. These are then used to inform the different elements of green roof performance in the Approach and DST to inform sustainable roof selection developed through this research.

3.6.3 Cool roofs

Cool Roofs are roofs that stay cool in the sun by minimising solar absorption and maximising thermal emittance (Akbari, 2008). The subject areas of cool roofs, Urban Heat Island (UHI) effect, urban air pollution, and building and city level cooling energy requirements are all highly interrelated. Literature on these issues is vast but much more work is required to implement findings and realise the benefits in the real world. An up to date and extensive list of publications regarding the above subject areas can be found at Akbari (2009).

The temperature extremes that roofs can experience is further stressed by Ramachandran, Paroli et al. (2002) who state that in the northern hemisphere, asphalt or black roof membrane roofs can reach up to 100°C on a hot summer day and as cold as -40°C in winter. This can have significant effects on both the cooling and heating demand of the building and the collective impact of roofs on phenomena such as the Urban Heat Island (UHI) effect. Whilst increasing roof albedo and infrared emittance can reduce energy consumption in hot climates, it may increase heating-energy consumption in winter months or in cooler climates (Akbari et al., 2008).

The parameters of a roof's surface can have a large influence on the surface temperature of the roof. During clear sky conditions up to around 1kW/m^2 of solar radiation can be incident on a roof surface, and between 20% and 95% of solar radiation incident on a surface is typically absorbed (Suehrcke et al., 2008). Surface parameters include the solar absorptance, infrared emittance, and the convection coefficient (Berdahl and Bretz, 1997). Roofs that have high solar reflectance (high ability to reflect sunlight) and high thermal emittance (high ability to radiate heat) tend to stay cooler in the sun (Akbari et al., 2008).

The colour of roofs can significantly influence the temperature to which the roof surface can reach. The albedo is often linked to the colour. For example the colour white is often effective in minimising heat transfer into a building as it is a poor absorber of energy but also a good emitter (Al-Homoud, 2005). The general idea of white washing structures to reflect heat has been known since antiquity (Berdahl and Bretz, 1997). The idea is to increase the solar reflectance (albedo) of the surface. The term albedo designates the total reflectance of a specific system. However, the colour is not always a good indication of the albedo of a surface as the albedo of a surface depends not only on its visible reflectivity but also on its reflection of Infra-Red (IR) light. The visible range comprises approximately 46% of the entire solar spectrum. The infrared radiation is invisible to the eye and comprises of approximately 43% of the solar spectrum. The nature of IR is mainly thermal (Prado and Ferreira, 2005). Thus a white surface is not necessarily cool, for example commonly used ‘white’ coloured roofing shingles and galvanised steel run 35^{o}C and 43^{o}C hotter than air temperature on a sunny day. On the other hand surfaces painted with red or green acrylic paint run only about 22^{o}C hotter even though they are not visibly bright (Rosenfeld et al., 1995). Galvanised mild steel gets hot, not due to its low albedo but because of its low emissivity meaning it is slow to cool by radiation (Rosenfeld et al., 1995).

For more detailed information on the performance of cool roofs see Appendix M.

3.6.4 Solar technologies

Solar Energy is a large subject area in its own right, this section wishes to present the technologies that are typically present for harnessing solar energy that is incident on the roof. As solar energy is both abundant and clean, it is receiving much attention in green building energy systems (Zhai et al., 2008). Typically the average energy made available for use at the surface of the earth is about 1000W/m^2. The range in the UK is between 900 to 1300kWh/m^2 (Keirstead, 2007). There are two main types of solar technologies that are applied to buildings at present, these include solar thermal and PV. Literature on the subject area is extensive. A good starting point is the book *‘Solar Energy: Fundamentals, Design, Modelling and Application’* (Tiwari, 2002). This section gives a brief overview of the two main types of active technologies to create useful energy to provide hot water, heating and electricity for the building.

Solar Thermal and PV technologies used in buildings are classified as micro generation technology. Such technology if integrated within buildings has to be placed on the building envelope. With solar thermal and PV systems this tends to be the roof for the following reasons (CIBSE, 2000, Elliot, 2003a, Bahaj, 2003):

- less likely to be overshadowed than the facade
- systems can be arranged to have optimum tilts and thus the highest performance
- often easier to install, however particular care may be needed to avoid water penetration
- systems are less vulnerable to vandalism
- urban areas do not have much free land, however they do have large amounts of roof space

Elliot (2003a) also explains that he expects the trend towards smaller more decentralised systems to continue with smaller power stations dispersed around the country right down to the individual house level. Drivers for decentralisation in some countries include individuals' desires to generate their own power so as to be less reliant on failing grid supplies. This became apparent in California in 2000-2001, when regular blackouts and price hikes followed the deregulation of the energy market (Elliot, 2003a).

3.6.4.1 Solar thermal collectors

Solar thermal collectors are those concerned with the conversion of solar radiation to heat to provide hot water. The overall system efficiencies vary, but typically around 30-60% of the energy from the sun can be delivered as heat to the taps. There are two main types of collectors which are as follows (Rawlings, 2009):

- ***Flat Plate Collectors*** typically consist of a dark absorber on which solar radiation falls and through which a heat transfer fluid can circulate. This is normally covered with a layer of glass. They are generally cheaper and more common that evacuated tube collectors
- ***Evacuated Tube Collectors*** are generally more efficient than flat plate collectors, but are also more expensive as they are more sophisticated devices. Their increased efficiency results from mounting the absorber in an evacuated and pressure-proof glass tube which reduces conductive and convective losses.

3.6.4.2 Solar photovoltaics (PV)

PV systems convert solar radiation into electricity. They have no moving parts and thus are a silent, safe and elegant way of producing electricity. This type of technology is particularly applicable to roofs with roof-top installations accounting for 66% of the world PV market today (Fthenakis, 2009).

It is often stated that there are three generations of photovoltaics that are currently in the market place. Most solar cells currently on the market are either mono or polycrystalline silicon based on silicon wafers (Green, 2002). They are often referred to as first generation technologies. Second generation PV includes thin film cell technology and occupies a small niche in the market with respect to its application on buildings. The third generation of technologies is currently at research and development stage and consists of organic cells (such as photo-electrochemical cells and dye sensitised cells) (Chiabrando et al., 2009).

This section will focus on the most common types of PV applicable to roofs, which are first and second generation PV technologies which include:

- Monocrystalline Panels
- Polycrystalline Panels
- Thin-film systems
- Hybrid Panels

Monocrystalline silicon and polycrystalline silicon panels are the most common type of PV. Mono crystalline are generally the most efficient and robust, but are also the most energy intensive in production. This lead to the development of polycrystalline cells which are slightly less efficient, but are also less energy intensive (Messenger and Ventre, 2004). The efficiency of thin-film silicon PV is significantly lower than other systems, however they use significantly less energy and material in production due to its thin nature. Additionally, due to the minimal thickness of this type of PV it can be used to create a flexible membrane by using plastics (Thomas and Grainger, 1999). Currently around 70% of the cost of manufacturing PV panels at present are material costs, therefore thin films offer prospects for a major reduction in material costs by eliminating the silicon wafer (Green, 2002). They are also sufficiently tough for foot traffic. Whilst there have been concerns in the past regarding the durability of thin film PV, there is no intrinsic reason why thin film technologies cannot match the durability of standard wafer based products. In fact recent results suggest that thin-film can match the excellent durability of standard wafer based PV and have actually outperformed wafer based systems in accelerated testing (Green, 2006).

The typical efficiencies of the most common types of PV are stated in Table 3—3. The most up-to-date efficiency tables for the majority of different PV types can be found in Progress in Photovoltaics journal which are updated every 6 months with data from test conditions (Green et al., 2009).

Table 3—3 PV efficiencies compiled from CIBSE (2000) and product datasheets that were assessed under standard test conditions

Type	Approximate cell efficiency %	Approximate module efficiency %
Monocrystalline silicon	13-17%	12-15%
Polycrystalline silicon	12-15%	11-14%
Thin-film silicon (using amorphous silicon)	4-7.5%	4.5-4.9%
Hybrid (combination of Monocrystalline silicon and thin film silicon)	See efficiencies above	17-20%

Although PV systems do not generate any toxic or greenhouse-gas emissions in use, they may produce impacts in their production. A summary of the emissions including CO2, potent greenhouse gases and heavy metal emissions during the production of various types of thin film modules is summarised in Fthenakis (2009). However, claims that suggest PV systems do not payback the energy (and associated emissions) used to manufacture them in life time are deeply miss-founded as shown by data presented by Varun, Prakash et al. (2009). When the typical thin-film PV system emissions per kWh of energy produced are compared with that of the present production methods of grid electricity, thin-film PV systems results in 89-98% reductions in the emissions of GHGs, criteria pollutants, heavy metals and radioactive species (Fthenakis, 2009).

For more information on how to assess the quantitative performance of PV systems please see Appendix N. This details the methodologies used to assess performance in the roof DST.

3.6.5 Rainwater harvesting

> *"Rainwater harvesting captures precipitation and uses it as close as possible to where it falls. The process mimics intact and healthy ecosystems, which naturally infiltrate rainwater into the soil and cycle it through myriad life forms. Instead of sealing and dehydrating the landscape with impervious pavement and convex shapes that drain the gift away, as most modern cities, suburbs, and home landscapes do, harvesting accepts rain and allows it to follow its natural path to productivity."* (Lancaster, 2008)

Cisterns harvesting runoff from rooftop catchments have the potential to harvest the highest quality rainwater runoff on site and allow for the greatest range of potential uses for that water (Lancaster 2008). It is becoming more common to install rainwater harvesting systems to capture grey water from the roof for uses such as flushing toilets. Methods for calculating runoff and sizing rainwater harvesting systems are included in BS8515 (2009). This considers three elements to sizing rain water systems, which are dependent on the following things:

1. The amount and intensity of rainfall
2. The size and type of the collection surface
3. The number and type of intended applications, both present and future

An approach for assessing the rain water harvesting potential of roofs is outlined in Appendix O. It considers the potential runoff from the roof and the associated benefits in runoff reduction and water use reduction for the building. It takes account of points (1) and (2) from the above list. However, it does not consider point (3), *“the number and type of intended applications”* as this is considered a building design issue rather than roof selection consideration, as it also considers the water usage of the building.

3.7 Roof decision making frameworks

Literature focusing specifically on sustainable and high value roof selection is sparse. However, there are five highly relevant publications from which this research can build. These include two Masters level thesis (McCourt, 2007, Nelms, 2005), one PhD thesis (Grant, 2007), and two journal articles in the subject area (Nelms et al., 2005, Nelms et al., 2007).

These pieces of work are reviewed and critiqued in this section under the names of the three main authors of the studies, whilst providing an explanation of how this work intends to address some of the short comings of the other elements of work.

3.7.1 Grant

The PhD thesis, titled “A Decision-Making Framework for Vegetated Roofing System Selection” (Grant, 2007) focuses on primarily green roof systems. The research provide a diagrammatic view of the decision process involved in the selection of vegetated roofing systems. The thesis is based upon a case study approach to identify six critically important evaluative categories for green roofs which include:

1. Storm Water Management
2. Energy Consumption

3. Acoustics
4. Structure
5. Compliance with regulatory guidelines and government incentives
6. And cost

These form the basis of her study. Based on these attributes she has developed a decision-making framework for green roof systems. She suggests that further work should seek to automate this framework by computational means.

This is no trivial task, with large quantities of data feeding in to complex calculations (in some cases) to understand how different systems perform. Additionally, she also lists several questions for further consideration and to progress the work she has undertaken. This provided a useful starting point for this research.

Many of these relate to the six categories of interest which are defined above and many involve techniques aimed at improving the understanding of how green roofs perform in these areas, in an effort to gain quantitative data that can be fed into the decision making framework that she defined.

Fortunately, research on the performance of green roofs has advanced rapidly since the submission of her thesis and some of these questions have begun to be addressed in more depth. Therefore, this research intends to take some elements of the framework, along with advances in the technical understanding of the performance of various systems and combine this to develop elements of the framework into a prototype tool. Additionally, whilst her research did refer to a “reference roof” against which green roofs could be compared, this was never defined and no other roof types were considered explicitly in her research. This is an important omission as essentially green roofs were not being compared to other types.

Her literature review considers some rules of thumb for the performance of systems for the six “evaluative categories”. However, the performance of a green roof in these categories is based on a large number of variables each one normally representing a specific element of performance that is context dependent. Whilst rules of thumb are used significantly in the early design stages, to be useful they have to be a ‘good enough’ representation of reality. If significantly removed from reality they can be meaningless or worse still, misleading. The rules of thumb Grant describes are generally only applicable for a particular context (climate type, roof types, etc.) and thus it is considered that ways of assessing the performance of different roof options which more closely represent their performance in reality are required. To address some of the limitations of Grant’s work, this research reviews international work and the different ranges of performances for different green roof systems in the different categories. The work also looks at ways of modelling the performance of different green roof systems to account for variations in performance that can be attributed to climate.

Additionally, the criteria in Grant’s case were specific to the Northern America context as they were derived from case study projects in this region. Therefore, whilst these characteristics may be applicable to other regions and contexts their globalised generalisation for all projects is considered premature. One such example includes consideration of LEED, which falls under “compliance with regulatory guidelines and government incentives”. Whilst LEED is used in some regions outside of North America, it is not a global system and these criteria may not be applicable in every case. This research expands on such systems to consider the environmental assessment methods such as LEED for North America and BREEAM and Estidama for other regions. However, exhaustively undertaking such a review of all different codes of practice and regulations and their relationship with roof design and selection is outside the scope of this work. However, this would be considered worthy further work in this subject area. Additionally, Grant notes the importance of being able to expand to consider different roof requirements, however does not provide a method of identifying what those might be for a particular project. This work also considers approaches for doing this.

Other limitations of Grant's research included the inability to combine different roof systems on one roofscape and no framework to account for this. Whilst this was not a research objective and is not applicable when considering purely Green Roof Systems in isolation, it is considered an important element in this research. For example, a designer may be very interested in how a green roof on its own compares to a green roof with a photovoltaic system installed above it. Or comparing several roofs which are a combination of roof systems. An example might be, how does a roofscape with 40% extensive green roof area with 10% hard landscaping, 20% dedicated for photovoltaics and 30% for solar thermal compare with a roof made up of the same systems but in different proportions?

3.7.2 Nelms

Other work with respect to the selection of green roof systems has been undertaken by Nelms et al. (2007) which builds upon earlier work by Nelms et al. (2005). The framework is developed on the four guiding principles of:

1. building system or component is not an isolated entity but a part of, and it has implications for, other systems within the building as a whole
2. framework must reflect the diverse set of values held by project stakeholders
3. majority of project costs occur after the construction and during the operation and maintenance of the building; hence, performance over the total life cycle of the project must be considered
4. all new and established technologies are subject to risks and uncertainties that must be considered explicitly relative to project objectives and individual stakeholder perspectives

These principles are particularly relevant to roof design and selection and the principles of sustainability requiring consideration of the needs and requirements of the stakeholders, the interaction between systems and the life cycle of the entire project. Her framework therefore utilises a three-dimensional 'space' for assessing sustainable technologies (see Figure 3—2). The framework consists of cells. Contained in each cell are the performance measures evaluated for indirect and direct impact (Z-coordinate) on the corresponding building system or component (X-coordinate) and the respective time phase (Y-coordinate). As one progresses through the project life cycle, more detail is considered and the x-axis (building systems or components) will expand as the design goes from considering systems at a high level to considering the components of those systems.

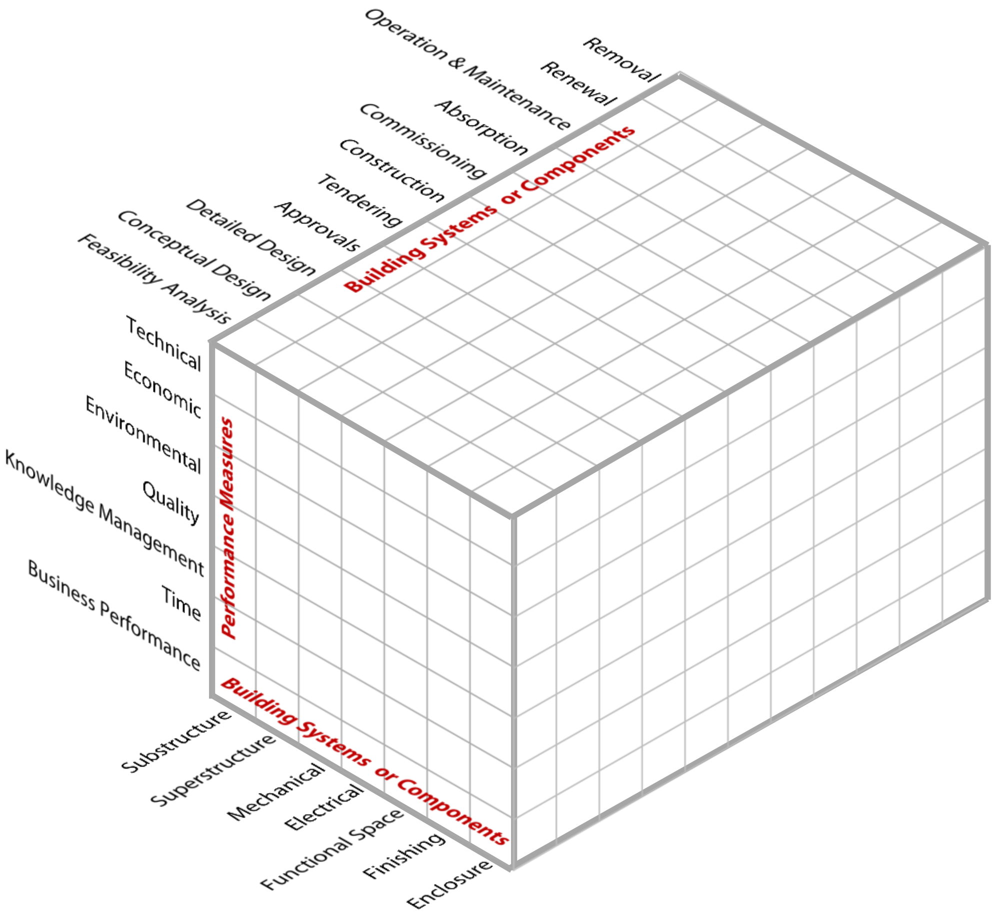


Figure 3—2 Representation in three dimensional space for assessing new technology after Nelms et al. (2005)

The framework is intended for use by design professionals, regulators, and government entities which span some of the same user groups as this research.

She synthesises work by Becker (2002), Lutz (1990) and Foliente (1998) which define criteria for the technical assessment of buildings. This includes a large number of considerations that span areas such as technical impact, environmental impact, economic impact, quality, knowledge management, time, business performance etc.

When utilising the framework to assess technologies, Nelms outlines a multi-phase approach:

- **Phase 1: Preliminary Screening - Regulatory feasibility and pass/fail judgements** on whether or not the technology may be suitable for further scrutiny are assessed. A critical evaluation based on user judgement of costs relative to benefits is made. The first phase of the approach involves an evaluation at a relatively aggregated or course level in terms of both the physical systems affected. This means that assessment is undertaken at the systems level rather than at the component level. This involves a technical and regulatory analysis (facts) of the technology and life cycle phases affected and critical evaluation criteria. An order of magnitude estimate of balance between costs and benefits (including incentives-subsidies)
- **Phase 2: Screening – Physical building systems or components are indicated as being impacted or not impacted** for all performance measures that have been indicated as being of interest with respect to project objectives. This should determine what physical components within each system of the building and life cycle phases are impacted. Sufficient design should be conducted to scope the parameters of the technology itself (quantity, mass, etc.) and an evaluation of a more comprehensive range of performance measures should be undertaken.
- **Phase 3: Screening – Technical analysis for each performance measure identified as being impacted is quantified using order-of magnitude functions** for the various phases in the project life cycle and a degree of uncertainty of this estimate is developed. Check that required technical and regulatory thresholds on performance are met.
- **Phase 4: Screening – Economic analysis** of the technology to price out associated performance measures using a variety of economic performance measures. Risk-adjusted values of key performance measures are determined.
- **Phase 5: Screening –Value analysis** of technology using technical scores multiplied by **value weights** is performed. This is values based rather than factual and should be based on the thoughts of the various stakeholders.
- **Phase 6: Final Screening/decision** is made on whether or not to implement the technology by comparing it with the default design approach.

Nelms applies this approach to the selection of green roof technologies. Nelms chose this technology because of the multiple interactions with building systems that it exhibits, the range of disciplines required for its design, construction, operation, and maintenance, and the range of benefits and implications for stakeholders. An example of Phase 2 of the framework is shown in the Figure 3—3. Systems directly related to the technology are shown in black, and the consequences of adopting the technology for other life cycle phases and components are shown as shaded.

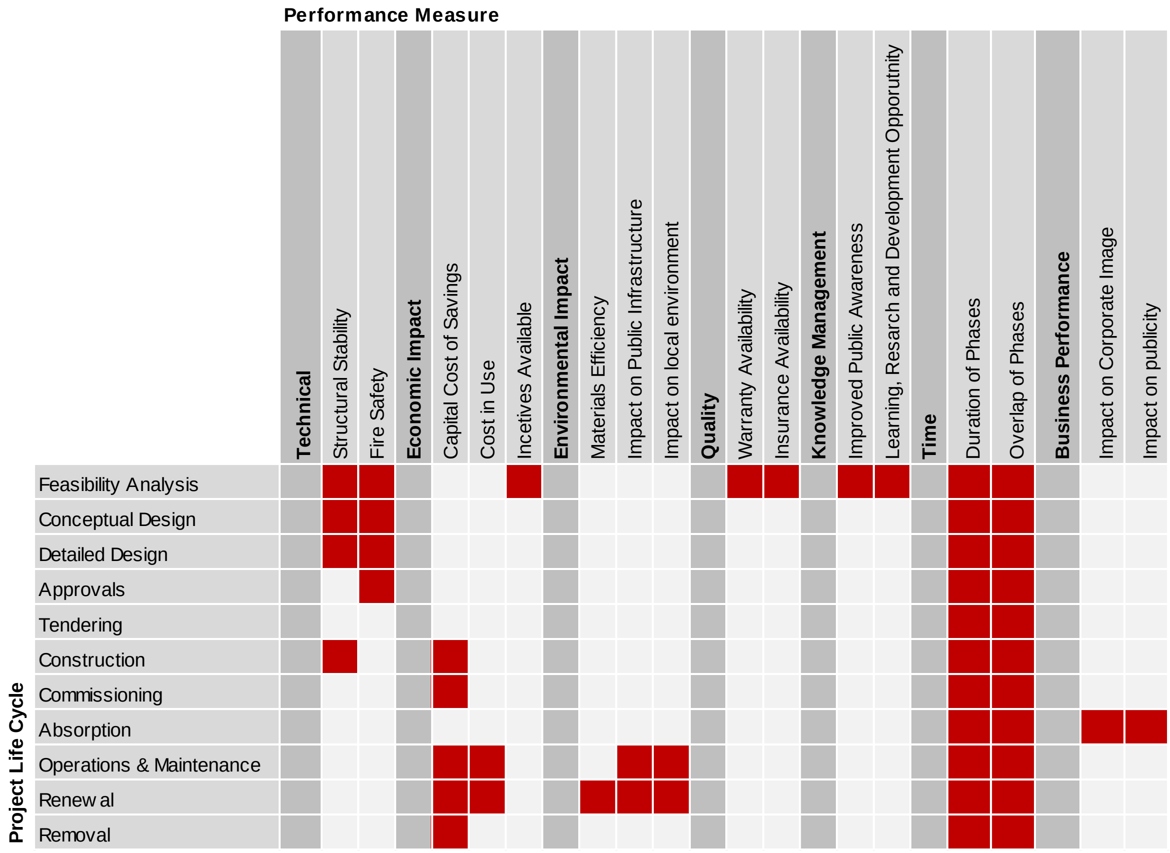


Figure 3—3 Technology evaluation matrix after Nelms et al. (2005)

A similar matrix can be used to show the y-z dimension of the three dimensional space as shown in Figure 3—4. This represents the performance measures for different phases of the project life cycle. Performance measures directly related to the roof systems are shown in black.

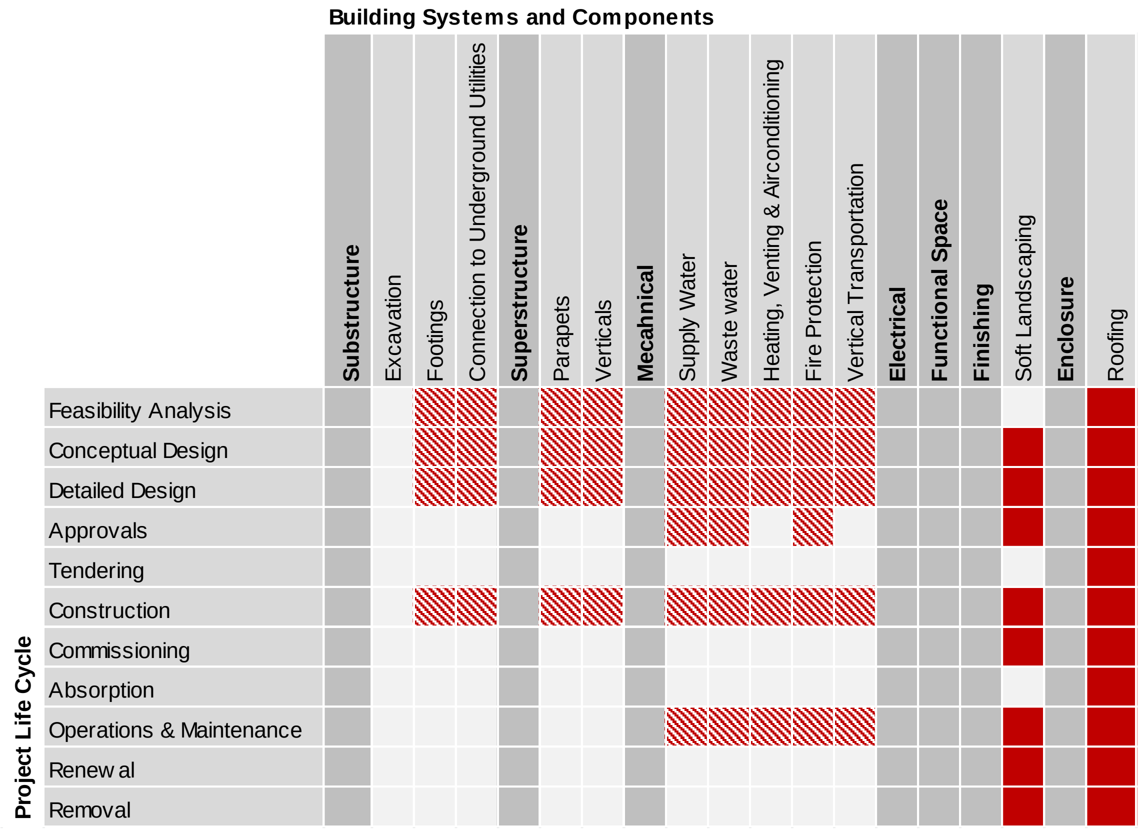


Figure 3—4 Technology evaluation matrix – two dimensional view of intensive green roof performance measures relating to roofing building system after Nelms et al. (2005)

Nelms' (2005) paper systematically demonstrates a process for identifying how a technology interacts with the physical design of a project and the associated project timeline. It also demonstrates the many performance measures that are affected by roof design and selection. However, it is not explicit about how these elements would be measured and the process for selecting which elements to focus on. Her paper identifies a multitude of measures, but through the tight time frames and limited budget for assessing technologies it is unlikely that a comprehensive method for assessing all performance measures at different times in the process would be able to be considered.

Furthermore, the paper tends to suggest that the elements of performance can be converted to an economic net present value (NPV). This would require significant information and assumptions and involve large amounts of uncertainty. Collaboration across design team members would require great coordination. This information also may not be available at the start of a project when decisions are required to have the greatest influence.

Nelms reflects on the process stating that, *“the impacts of such technologies may be both complex and difficult to quantify, and therefore our vision of a systematic evaluation framework has been presented as a tool to justify and communicate technology selection and stakeholder objectives.”*

Nelms further develops her thinking in her 2007 paper which seeks to further apply the framework considering the green roof context. This paper demonstrates an application and shows the type of information required at each step of the process.

She conducts interviews to understand the areas of interest of three stakeholder representatives. These are explained in the paper and a table, based on the criteria for technical assessment of the performance of building systems as further developed from Becker (2002). This highlights some of the difference across stakeholder groups. She also asked the stakeholder representatives to choose three impacts considered critical from their perspective when evaluating green roofs. Whilst this was for a hypothetical project, it is encouraging to see stakeholders involved in the decision making dialogue from this author’s perspective. However, other than asking which three impacts were critical, there was very little consideration of prioritisation of objectives which is beneficial when structuring decision problems. For example, the table demonstrated in her paper, simply has “X” next to the Performance Measure that they considered of interest. However, it did provide information on which performance measures were considered more important than the others. This approach would have significantly benefited from a form of ranking, or pairwise comparison applied to the process. Additionally, the six stage approach does not explicitly state the consideration of user values at the start, which seems inconsistent with the approach taken.

Interestingly the impacts of interest, whilst somewhat reflecting those outlined by Grant (2006) do differ. Therefore, this tends to suggest no one size fits all approach.

However, in both cases a predetermined framework has been applied. In both cases the requirements for assessment are not built from the values, needs and requirements of the project stakeholders for the project in question, but instead from either past project experience / case studies (in the case of Grant) or from predetermined checklists to assess the performance of building systems (Nelms). It is recognised that in the case of Nelms this was used as a stimulus and stakeholders then expressed the areas which they felt relevant with respect to green roofs. Phase 5 of the process allows users to input values through weighting to reflect importance of ‘performance measures’ to the decision. However, the performance measures have been defined through a review of papers rather than by the stakeholders they may appear abstract from the perspective of the stakeholders. Additionally, it is not entirely clear on how this should be done, as this is explicitly not considered in Nelms et al. (2007).

Additionally, whilst Nelms utilised interviews to elicit stakeholder preferences, no consideration of the process of eliciting stakeholder values through weighting was detailed in her work Additionally, whilst generalised comments were in many cases used, along with the knowledge of the performance of green roof systems under the categories defined as important in the decision making / assessment process, there was little explicit consideration of alternative roof options considered in either case. Therefore, one could argue that whilst there was significant consideration of the framework to account for the interactions between different elements of performance between the roof and other building systems, there was little evidence of how this could be applied or how this demonstrated either value-focused thinking or alternative focused thinking to inform decisions across numerous roof systems. Utilising the approach that is advocated of converting all elements of performance to NPV in cost terms, would mean that stakeholders are weighting the importance of the same unit, which appears to be a difficult thing for stakeholders to do.

No sensitivity analysis was undertaken and performance was based on rules of thumb only. However, Nelms et al. (2007) states that further work is required to refine the framework and develop related tools, such as a complete suite of order-of-magnitude estimation models that are easy to use and provide insight into technology performance.

In summary, Nelms et al. (2007) is considered a useful high-level framework of what to consider and when during the design process with respect to green roofs, but not an accessible approach to supporting decision’s with respect to roof selection from a sustainability perspective.

3.7.3 McCourt

The only other evidence of explicit consideration of roof decision making that has been found in the literature was a master's thesis, titled, "A Decision Model for Selecting Energy Efficient Technologies for Low-Sloping Roof Tops using Value Focused Thinking" (McCourt, 2007). McCourt (2007) utilises value focused thinking to determine appropriate roofing. The purpose of the work was to provide air force decision makers with a tool to assist them in deciding which roofing facilities should be installed on US Air Force Base Facilities.

The following 10 stage process was utilised as a methodology for the research:

1. Problem Identification
2. Create Value hierarchy
3. Develop Evaluation Measures
4. Create Value Functions
5. Weight Value Hierarchy
6. Alternative Generation
7. Alternative Scoring
8. Deterministic Analysis
9. Sensitivity Analysis
10. Conclusions and Recommendations

Attention is given to roof alternatives at Stage 6 in the process. The performance of the different options is only considered at stage 7 after significant consideration of the problem situations and value functions to frame the decision. This is in stark contrast to alternative focused thinking which normally involves identifying alternatives for consideration, before then scoring those alternatives based on performance.

In order to understand the requirements and values of the decision maker the work utilised interviews with three different air force base engineers across different bases. These involved general discussion of the problem situation, but also included a brainstorming session with each to determine what was valued in energy efficient roofing technologies. The following generalised questions were asked:

- What do you value/want in roofing technologies?
- What is your ultimate objective?
- What would you like to achieve in this situation?
- What are your values that are absolutely fundamental?
- What objectives do you have for your customers?

- What environmental, social, economic, or health and safety objectives are important?

The resulting output of the sessions was refined and developed into a value hierarchy as shown in the figure below:

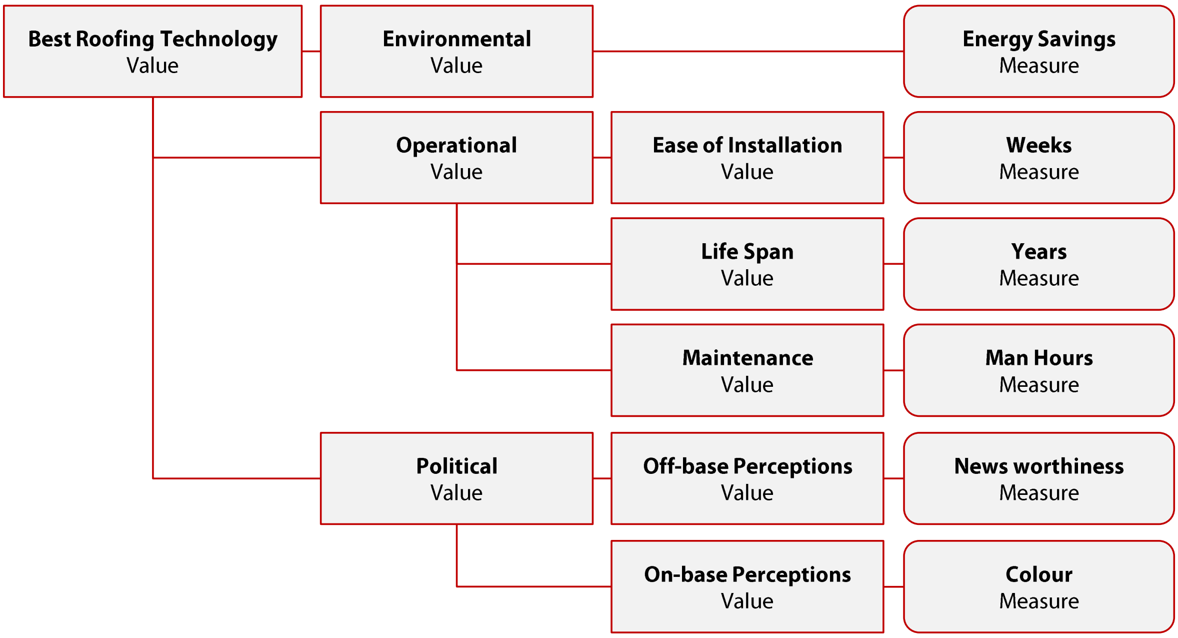


Figure 3—5 Value hierarchy for selecting energy efficient roofing technologies after McCourt (2007)

For each of the lowest tier elements, value functions were then defined. These convert each element into a value between one and zero for scoring the alternatives. He used a combination of discrete and continuous value functions depending on the criteria.

The next step involves weighting the value hierarchy. Many techniques are available to do this. The technique used in this case include the 100-point method. This was done by providing each decision maker with 100 poker chips, and instructing them to distribute the chips to assign importance to achieve value in a tier. This is easily implemented and a useful way of eliciting the areas of prioritisation. However, it does fall short, in one area of consideration, which is referred to by Ralph Keeney as the “most common critical mistake” (Keeney, 1992) (p147). This is that it doesn’t take account for the scoring of alternatives in considering the weighting. Keeney (1992) gives the following example:

> *"When we quantify objectives by simply asking for their relative importance, considerable misinformation about values is produced and a substantial opportunity to understand values is lost. The importance of an objective must depend on how much achievement of that objective we are talking about. Clearly a cost of $200 million is more important than a cost of $4 million. So if somebody asks whether the environmental risk at a hazardous waste site is more important than the clean-up cost, it should make a difference whether the cost is $4million or $200 million."*

Keeney goes on to argue that some information is required to understand values;

> *"In this air pollution problem, which is more important, costs or pollutant concentration? Almost anyone will answer such a question. They will even answer when asked how much more important the stated "more important" objective is... for instance, a respondent might state that pollutant concentrations are three times as important as costs. While the sentiment makes sense, it is completely useless for understanding values or for building a model of values. Does it mean, for example, that lowering pollutant concentrations in a metropolitan area by one part per billion would be worth $2 billion? The likely answer is of course not."*

Whilst, it is understandable, that McCourt applies the technique that he does for simplicity, perhaps there should be a stage in his approach to re-evaluate the weightings depending on the scores of the different options.

Alternatives were then generated. This included twelve systems that were picked for a variety of reasons. Some of which were to provide benchmarks that represented a significant proportion of the current stock of US Air Force base roofs. This provided a good basis for comparison. Others were selected because of their leading performance in aspects defined as important. In other words, the identified values were used to construction the alternative options.

Scores were then given for each of the twelve alternative roof types for three different context which represented different air force bases. The performance of each roof type was calculated for each specific context using a variety of means. For energy specifically, modelling tools were used. This allows the results to be context specific. Whilst these were at simplified level the author considers the approach to be used to be appropriate at the time this work was conducted. Whilst energy savings were modelled using a combination of techniques including the building simulation package eQUEST and the cool roof calculator (Oak Ridge National Laboratory, 2005). Neither have the ability to model green roof performance explicitly nor is any reference given as to how this has been accounted for. Other aspects were given values, based upon information from the literature reviews or interviews with experts, for example, in the case of news-worthiness. Due to the different contexts and weightings given for the values at different bases, along with different performance levels of the alternatives (due to their context specific nature), different outcomes were shown for the three individual Air Force regions considered.

A deterministic analysis was then conducted which seeks to understand the performance of each option in each of the evaluation categories. Finally, sensitivity analysis was conducted. Sensitivity analysis was used to determine the impact of changing the weightings of value functions (decision attributes) on the scoring of alternatives. The analysis was performed by changing the weight of one value, while keeping the ratio of the remaining values. This essentially gives the decision maker an idea of how much a particular weighting would have to change to modify the ranking of the different roof options.

In summary, McCourt successfully applied value focused thinking to frame the decision problem of selecting energy efficient low sloping roof systems. The research approach was to involve stakeholders in the definition of the decision criteria and weightings. The context appeared to be in a particular context of roof refurbishment, rather than new build projects and seemed abstracted from a typical design process. For example the work was conducted in the context of the US Air Force, and the analysis was being done by the US Air Force, presumably with them also being the owner occupiers of those buildings. This is not common for typical construction projects, which normally include a large number of stakeholders and a design team that may include a large number of professional groups. For example, an architect, project managers, various types of engineer, client representative, etc. Little reference was given to the typical project life cycle. This piece of work focuses the decision tightly around roof selection, and was less concerned with the relationship of the roof on other building systems. For example, no consideration was given as to the impact of green roofs on the structure of the building, an important consideration when considering potentially heavy systems such as green roofs. The range of criteria was limited and ignored many aspects often considered important in roof selection.

3.8 Summary and research gaps

The literature review starts by considering ‘what is a roof’ and ‘why is a roof important’. It explains that roofs provide a fundamental human need, protection. However, they also offer a multitude of possibilities for improving the sustainability of the built environment. It explains the historic development of roofs; from initially being made out of what was locally available to there now being a multitude of options and also a much greater awareness of the problems that different roof selections can both contribute to or potentially address. If roof systems can be better selected, they present the possibility of not only being ‘benign’ to the environment, but actually providing positive environmental, social and economic benefits. It is for this reason that improved roof design and selection offers a high leverage solution in developing a more sustainable future. Despite this, improved roof design and selection has not been explored in significant depth. The above reasons informed the choice as to focus on the roof, and how roof decisions can be improved from a sustainability and value perspective.

The literature review highlighted that there are many different areas which are influenced by roofs that are generally considered to be areas of interest with respect to sustainability. There are also methods that are emerging from the literature to understand the performance of roofs in these areas. A more detailed review of these is included later in the thesis with respect to the specific aspects of performance. However, there has not been much attention devoted to drawing this information together and less focus still on how to inform more sustainable decision making with respect to roof selection.

Past focus has been typically context specific with limited generalisability. This is of limited use to the design consultant working in the international arena where projects require rapid decisions in many contexts around the world and for roof systems that perform significantly differently depending on the climate.

Therefore, this research wishes to explore the possibilities that roofs offer to improve the value and sustainability of buildings. It is concerned with the roof as a system, explicitly connected with the building requirements. It considers flat roofs (with a pitch of less than 10°). It then considers the roof system from the top protective surface membrane upwards, and thus also considers systems that can be placed on the roof and the functions that these can provide.

The literature review then considered traditional roof systems before focusing on roof systems that are generally discussed with respect to addressing common sustainability issues.

There are many roof systems and technology options that can improve the sustainability of buildings and can provide much more than the original protective function of the roof. This is evident by the large range of roof systems that are currently in the market place. They include cool roofs, green roofs (many types), rainwater harvesting and the installation of solar roofs. The benefits of such roof systems include the reduction of the input and output flows to the building system. Benefits of reducing these flows include; decreased surface water runoff volume of the roof; decreased heating and cooling demands of the building; increased local biodiversity; increased durability and lifespan of the roof; improved local air quality; decreased Urban Heat Island (UHI) effects; improved roof life span, etc.

All of which have impacts on the environmental, economic and social performance of the roof and the building as a whole. However, the question of how much different roof systems improved various flows is not a simple one. Research on green roofs is rapidly advancing and understanding the performance implications for a particular context is currently difficult. There is a significant amount of research that is not categorised and from the perspective of the challenges of the design process highlighted in the first part of the literature review poses significant problems in being able to select the most relevant piece of performance information for a particular project.

Individual studies across the literature have often focused on just one type of roof in isolation, on one type of performance characteristic, in a specific context. Additionally, there is a lot of siloed research into how roofs perform in specific areas. This includes research into their energy performance, impact on urban heat island effect, runoff, design life etc. However, there is little structure to the research and no categorisation process on performance. It is therefore difficult from an academic perspective to identify areas that require further work with regards to specific experimental based research or in the case of industry to quickly identify the most relevant research for a specific context. However, very little has been done looking at how to synthesise this wealth of research to inform roof decision making. This is a significant gap in the past research and this research looks to address these gaps and contribute to knowledge in these areas.

The impact of roofs are then reviewed against three environmental assessment methods that are commonly used across the industry, to understand the way in which their performance is accounted for through such systems.

The review then considers and critiques work that aimed to define a list of tenets of a sustainable roof. The list was considered to be useful in some respects, but also limited in others. For example, the definition found was trying to be applied generically, however with respect to aspects of economic or social performance the context of a project is considered to be very important. Additionally, in some areas, such as discharging water from the roof as quickly as possible, the tenets were considered to be against some of the principles of more environmentally friendly roof options such as green roofs or ‘blue’ roofs which are designed to increase lag times through temporary storage of rain. This suggests a global generalised set of tenets of sustainable roofing are difficult to achieve.

Finally, the research reviewed other work that overlaps with this research with respect to informing roof selection. The author is aware of five pieces of work that have been conducted in this area by three main authors. These studies provide a good starting point for this research. The studies were all undertaken in the North American context and all, to some extent ,used rules of thumb in their analysis. These are briefly summarised below along with identification of the gaps that this research seeks to address.

Grant's (2007) work used six case studies to select six criteria for the assessment of all green roofs. She focused primarily on green roofs and the selection of different green roof systems rather than wider consideration of other possibly competing roof systems such as cool roofs, solar photovoltaic, and more traditional forms of roofing. This is a significant limitation. Additionally, stakeholders did not have the opportunity to consider wider roof attributes of interest. In her research which consisted of three follow up interviews to test the applicability of her framework, some elements were consistently not considered appropriate. These included acoustic performance in every case, tending to suggest that this is not typically valued in green roof selection. This is contradictory to her case study work which highlighted that acoustic performance was a common value. The discrepancy shows the need for stakeholder input into the selection of roof attributes for a specific context. Additionally performance was typically considered using broad rule of thumb considerations and little consideration of how to consider climate was shown.

Nelms (2005, 2007) provides a good summary of the wider building systems affected by roof design and selection along with when these should be considered in the design process, but didn't offer a clear way of scoring the performance of different roof options. Her work proposed conversion of all elements of performance into a NPV, which would be extremely time consuming and would also potentially cover up important trade-offs that may need to be considered by the decision maker. It did however advocate a stakeholder approach to considering the issues of roof design selection and provided a framework through which many members of the design team could potentially discuss the interconnectedness of green roof design and selection.

The values based approach used by McCourt (2007) has advantages. However, the weighting method asked stakeholders to weight the importance of attributes without knowing the performance differences of the roof systems across each attribute. This is considered as the “most common critical mistake” (Keeney, 1992) (p147) and is discussed in more depth in Section 3.7.3. The way in which criteria are selected in the design process could be further developed to engage groups of stakeholders, rather than singular stakeholders through interviews. This has been done in the US context for several different combinations of roof types, this was a very focused study looking at the impact of roof selection on US military bases. This is removed from a typical design process. Additionally, the work did not utilise the vast amounts of data currently available and used rules of thumb that are not generalisable to the global context. The development of a suite of order of magnitude estimation models that are easy to use is considered an area of further work. This is also acknowledged by Nelms et al. (2007). Therefore, improved methods of gaining appropriate information through identification of relevant research data or modelling would be beneficial.

Modelling techniques have moved on significantly since the research of Grant (2007) McCourt (2007) and Nelms et al. (2007), however modelling is still only typically done in the later design stages for compliance reasons rather than informing the design process. Developing simplified approaches to be able use the results of modelling rapidly at the start of the design process would be useful and is an area which is further developed through this research.

Across the literature there was very little consideration of roof design and selection from a project design perspective. The above approaches were looking to apply techniques into the project context without any significant consideration of the challenges of the design process. Some generic challenges of the design process in relation to buildings were identified in the literature in Part 1 of this thesis (see Section 2.3.3), however there was little consideration of how this relates to roof selection.

The above research gaps have led to the development of the following areas of further work:

- Consideration of the typical design process and the associated challenges of roof selection. For example, the opportunity for integrating sustainability is most cost effective at the earliest stages of design. However, this is typically when information is the most limited. Therefore, developing techniques to categorise and identify the most relevant information for assessing roof performance in different contexts with respect to sustainability consideration is important.

- Consideration of how sustainable roof selection can be linked to the values of a broad range of project stakeholders, or to helping the project as a whole achieve value.
- Development of an approach to roof selection and accompanying prototype decision support tool that allows consideration of bespoke project specific characteristics, linking the performance attributes of roofs to project objective as defined by stakeholders.
- Developing a technique to consider a broader range of roof options, i.e. expanding on work that considers for example, just green roofs as well as an approach for combing roof options.

These have helped identify the research questions as detailed in Section 5.2 and through addressing such questions the research presented in this thesis addresses these research gaps.

The next section of the literature review outlines techniques which have been applied to structure complex issues and aid in decision making in complex contexts. When combined they form what this author has termed “pragmatic realist” approaches in that they can be combined to bring together “values” and “facts”. Additionally, approaches to analysing decisions with multiple objectives are then reviewed. The intention is that such approaches can be applied in the context of this research in defining what represents sustainability and value in the context of buildings and help inform decision making with respect to the performance of different options, which in the case of this research will be to consider roofs.

3.9 Conclusions

This section has reviewed the literature to consider the roof and why it is important from a sustainability perspective. It has given a brief history of roof design, selection and construction and looked at the impact of roofs on typically used environmental assessment methods, which are the main drivers for sustainable design in the building industry at present. Then several roof system types are reviewed and assessed for how they can impact on typical sustainability considerations, as detailed in the literature. Then three roof decision making frameworks are reviewed before research gaps are identified. Several research gaps were identified of which the following will be addressed through this research. These are as follows:

- The limitations of current decision support methods for roofs.

- The lack of a structured approach to acquiring roof performance information to reflect the project's context.

These are considered in the development of the research questions and objectives in Section 5.2. The next section considers techniques from other disciplines for decision making in complex contexts, with the intention of understanding what has been done in other disciplines which could have potential in the building industry.

4 Literature review: Identifying decision support methods for complex contexts

4.1 Introduction

As this research is ultimately interested in approaches to structure and support more sustainable decisions within the project context, this section considers different approaches to structuring decisions and making decisions between options. The aim of this literature review is to find techniques which may be applicable for application in this research. This literature element of the literature review, considers the limitations identified with respect to Environmental Assessment Methods, in enabling sustainability decisions on projects in the building industry. These include their inability to incorporate the values of stakeholders and local and contextual knowledge, an over focus on environmental issues, and aspects which are easy to measure. In doing so it is considering approaches from the broader literature which may be useful in addressing some of these issues. As the ultimate aim of the research is to be able to support sustainable roof selection, a range of techniques aimed at defining criteria relevant to stakeholders are reviewed.

4.2 Decision problems and decision support

A more quantitative approach is outlined by French and Geldermann (2005), albeit from an environmental rather than sustainability perspective. In their paper they consider many different decision analytic techniques and methodologies and assess their appropriateness in relation to different contexts to which they might be applied. They draw conclusions to help others develop appropriate decision analysis and support processes for environmental problems. They break the decision context down into three broad areas which include; (1) the problem context; (2) cognitive factors; and (3) the social context. They then detail a generic decision analytic cycle with three phases and associated sub-activities:

a. Problem formulation - formulate and structure the problem and issues
b. Evaluation of options,
c. Review of the decision models

They state the ubiquitous nature of such activities and liken the process to LCA, which has a Goal and Scope Definition Stage (formulate problem), Inventory Analysis and Impact Assessment (evaluation options) and an interpretation stage which could be, depending on context, considered similar to the “formulate problem” or “review decision” structure phases of multi-criteria analysis (British Standards Institution, 2006, French and Geldermann, 2005). French and Geldermann (2005) explain that there is a wide range of methods of analysis that when working with decision makers, stakeholders and experts can be used to identify objectives, key stakeholders, potential consequences, key uncertainties, contingencies and dependencies, constraints, confounding issues, etc. Additionally during the problem formulation stage decision makers can utilise soft modelling methods known under various names that have been developed over the past 20 years or so to help in problem formulation. Through this process uncertainty needs to be addressed and ideas explored and any particular aspects that require modelling should be clarified. Such techniques are discussed in more depth in the Section 4.3.2 regarding Problem Structuring Methods (PSMs), with the aim of distilling aspects which could be used to structure decisions in relation to roof selection.

However, the first step in the decision modelling separates the science, what might happen as a result of possible actions, from value judgements of how much each possible consequence matters. This essentially separates the difference in the roles of the experts and stakeholders in the decision (Keeney, 1992, French and Geldermann, 2005).

Values are incorporated through value judgements defined by stakeholders. These essentially set the objectives and these should be incorporated into an attribute tree. At this stage the important pieces of data, the ways of measuring the success of each option in relation to each attribute, should be identified. Scientific quantitative analysis should then be used where appropriate to provide data in relation to specific metrics to incorporate into the decision making process. This may involve for example utilising tools such as LCA to quantify the environmental impact of each option, considering the various social implications of each option and undertaking a Life Cycle Costing Analysis. A schematic showing the various aspects of the analysis required for the evaluation of options, including consequence modelling, statistical analysis and decision analysis is shown in Figure 4—1,

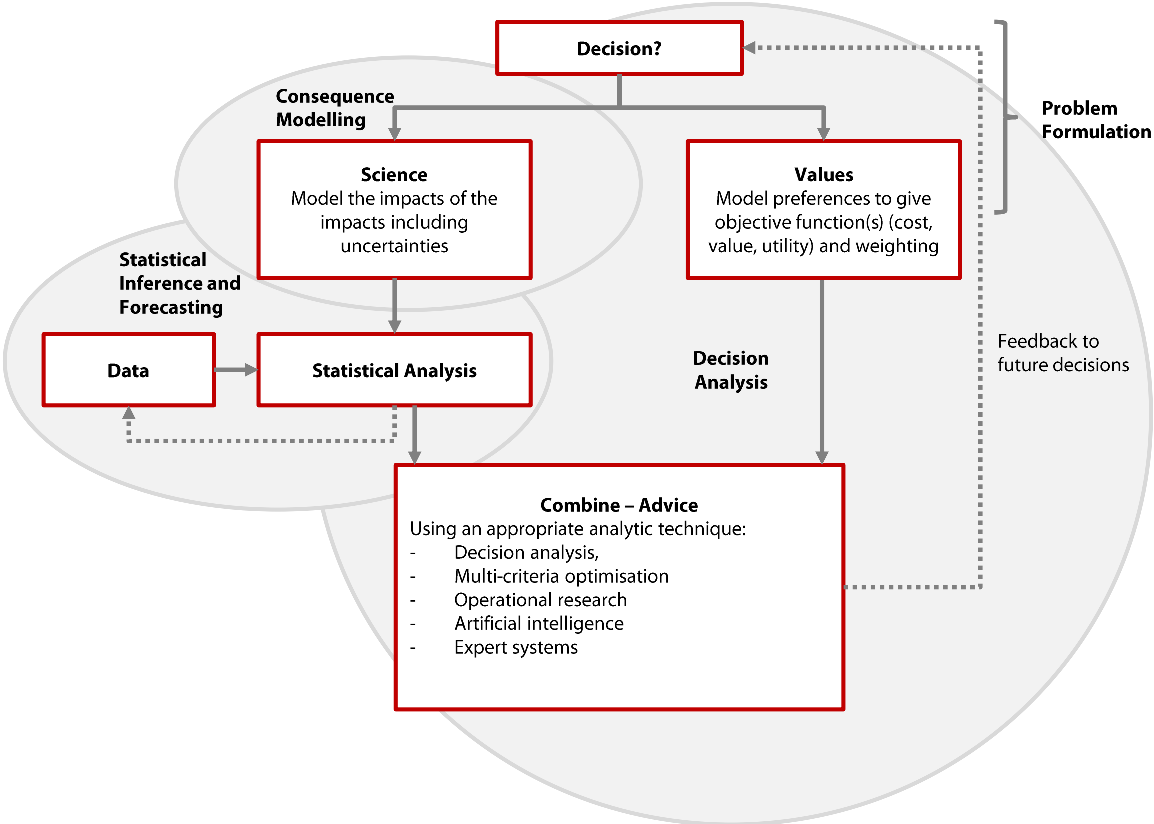


Figure 4—1 Analysis underpinning the stage "evaluate options" after French and Geldermann (2005)

French and Geldermann (2005) explain that sensitivity analysis should then be undertaken. There are two reasons that they state for this:

1. It helps decision maker, analysts and stakeholders assess the importance of broad uncertainties in their data and models. It helps understand where there is a strong basis for making a decision or whether more data is required.
2. It can help build consensus between decision makers and stakeholders. For example if a group are concerned that alternatives had been ranked inappropriately, but sensitivity analysis showed that taking extreme alternative positions does not change the ranking, then this can help build consensus.

French and Geldermann (2005) contribution provides a way of categorisation of a variety of decision methods with respect to two dimensions; degree of structure, ranging from highly structured repetitive decisions to relatively unstructured one off decisions (as is typically the case with environmental decisions); and the level of decision support required, which ranges from Level 0 to level 3. Level 0 is the minimal amount and is described as simply, "*acquisition, checking and presentation of data, directly or with minimal analysis to decision makers."* Level 3 involves, *"evaluation and ranking of alternative strategies in the face of uncertainty by balancing their respective benefits and disadvantages."* Their categorisation is shown in Figure 4—2.

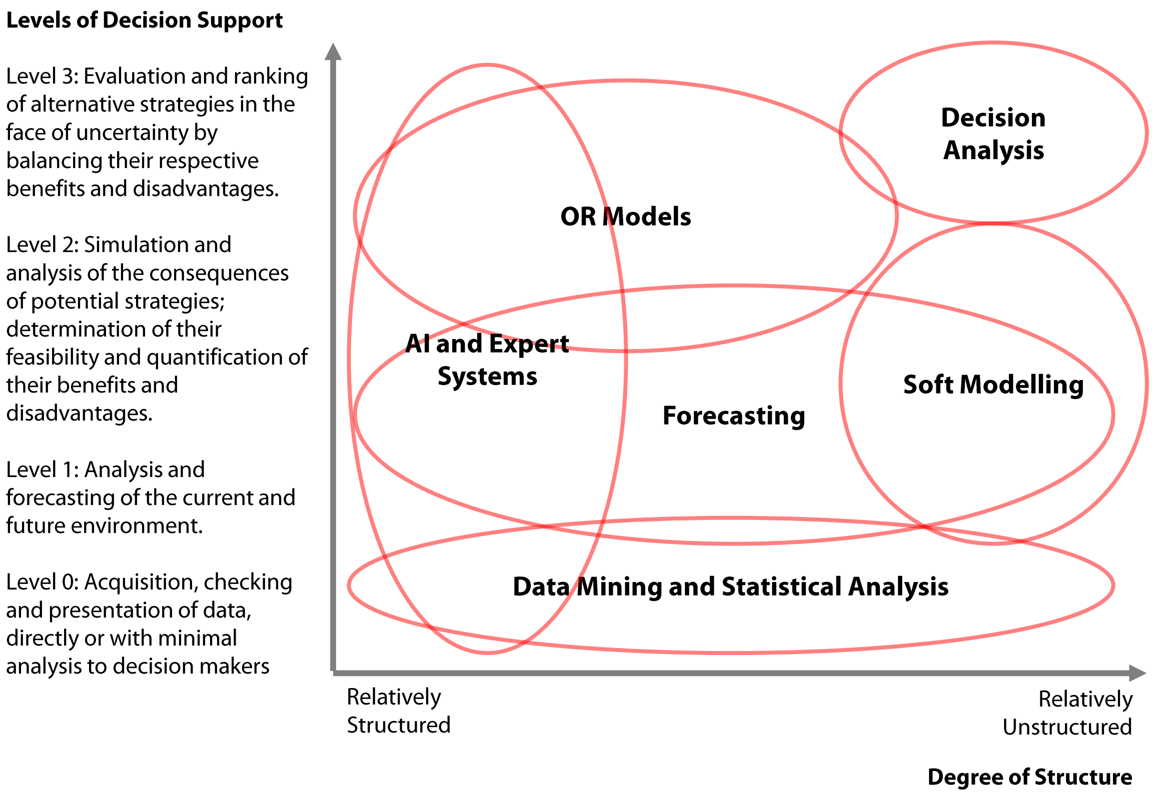


Figure 4—2 Categorisation of a variety of decision support methods after French and Geldermann (2005)

With respect to informing sustainable roof selection, it is considered that the decisions are relatively unstructured and ideally further work would provide Level 3 type decision support. Therefore in the case of this research Decision Analysis is identified to be an appropriate technique. However, it is argued that in the context of this research in order to undertake decision analysis, other methods will be required in order to gain the relevant information to be able to undertake decision analysis that provides level 3 decision support in relation to objectives considered important for the project context. Therefore it is considered that Soft modelling techniques should be reviewed to consider how they can provide the necessary structure and objectives. Additionally, how techniques such as data mining and statistical analysis and forecasting can be undertaken to help provide the data to inform a decision analysis will all potentially play an important role in an overall approach to sustainable roof selection.

Approaches aimed at structuring and informing decisions can be applied to sustainability and provide a means of combining the values and objectives as defined by stakeholders with the scientific performance of options to assess the most suitable course of options. As action orientated approaches combining science and values, they are considered by the author to be pragmatic realist approaches. However there are some contrasts to the pragmatic realist approaches to sustainability discussed in Chapter 2.2.2.3. Approaches such as TNS and DesignWays combine elements of stakeholder participation, incorporation of values and scientific principles. They all have an action orientated approach. However, the differences between the approaches are worth making explicit in clarifying the stance of this author throughout the remainder of this thesis.

Pragmatic realist approaches such as DesignWays and The Natural Step's Backcasting methods both take a strong sustainability stance. TNS framework's systems principles being applied in both. The decision making approach outlined by French and Geldermann (2005) does not take a strong sustainability approach, suggesting that a range of problem structuring methods are instead used to define the overall objectives, but does not necessarily have an emphasis on maintaining or enhancing natural capital above other forms of capital.

Additionally the decision analysis approach, does not focus on developing courses of action, it instead aims to understand what is important and provide a way of assessing alternative courses of action. The DesignWays methodology however includes a stage which is specifically looking at the root causes of problems and identifying solutions to those problems through creative thinking techniques used with project stakeholders.

Other differences include the DesignWays methodology and TNS Backcasting method not necessarily involving quantification, although quantitative tools are not excluded from the approaches. Therefore it is argued that they take more of a “Soft Modelling” approach to sustainability as classified using the framework defined by (French and Geldermann, 2005) detailed in Figure 4—2. Tippett et al. (2007) explains the DesignWays approach instead qualitatively tests options against the TNS system conditions. In contrast to this Decision Analysis proposed by French and Geldermann (2005) which has a more quantitative focus, with explicit scoring and evaluation and ranking of alternative strategies.

DesignWays also include education of stakeholders explicitly in the process and in doing so teaches participants about the TNS system conditions and also incorporating them into the formulation of options. This is also true of the TNS Backcasting methodology, which involves defining a framework for sustainability as the first step, which includes teaching the TNS systems conditions to participants. Whilst stakeholder participation is seen as an important aspect of decision making in the French and Geldermann (2005) paper, there is little emphasis on stakeholder education. Instead, focus is given to understanding stakeholders’ perceptions and values and taking those into account in the decision making process rather than upskilling and educating the participants. Experts then support the decision-making process by providing information on the content of the decision; whilst analysts provide process skills, helping to structure the analysis and interpret the conclusions. This has a different emphasis, and whilst French and Geldermann (2005) acknowledge that the separation of roles they describe is very idealised, the roles exist and the analysis of performance and the development of options has an expert driven rather than a broader stakeholder driven emphasis.

This approach is supported by Keeney who explains that in public problems, *‘values, rather than facts are the aspect of the problem about which many members of society will have knowledgeable viewpoints’* (Keeney, 1992). This author believes that people can grapple with the factual, scientific aspects of sustainability or decision making, but the quantification of how options perform in relation to values, is typically done by an expert. In the case of the performance of building components and systems such as roofs, degrees in various different disciplines maybe required to understand some of the processes that are involved from a comfort and energy perspective, runoff perspective, the quantification of biodiversity, etc. Whilst, this information has to be understood by stakeholders in relation to their values, the assessment of the quantitative performance of each option does not have to involve their input. This explains the separation of values and science in Figure 4—1 and the general approach to this thesis.

Additionally, whilst there is not explicit focus on education of stakeholders in decision analysis, Ewing and Baker (2009) note that the collaborative process of developing a green building decision support tool with students had an educational value. Finally, it is considered by French and Geldermann (2005) that decision analysis offers evaluation and ranking of alternative options quantitatively, and this is something that is not included in either the TNS Backcasting Approach or the DesignWays methodology. However, emerging from the work by Robèrt (2000) is a framework for structuring the tools and concepts for sustainability and how they relate to each other. This includes categorisation of a strategy for sustainable development, activities that are part of that strategy and concepts and tools (metrics) which can help measure progress towards sustainability. Whilst, there is an emphasis by Robert (2000) on strong sustainability working from TNS systems principles, many of the aspects in terms of providing a way of structuring the debate between sustainability, sustainable development, actions and metrics are considered useful by this author for structuring this work.

In the approaches there are discrepancies to the extent of stakeholder participation, however the requirement to engage stakeholders in decision making is common to all the pragmatic realist approaches to sustainability discussed above. Additionally, all approaches emphasise the need to structure the problem. Therefore a combination of soft modelling (utilising problem structuring methods) to consider the decision objectives combined with decision analysis is considered appropriate for this research. The next section considers, stakeholder engagement/participation and problem structuring techniques as a way to formulate the problem.

4.3 Problem formulation

4.3.1 Stakeholder engagement and participation

The literature review highlighted the need for sustainable assessment techniques in the building industry to integrate values, needs and preferences of stakeholders into the design, delivery and operation of the built environment. This has also been identified as key to pragmatic realist approaches to sustainability. Therefore this section considers approaches to engaging stakeholders as discussed in the literature to inform the selection of approaches to aid in problem structuring and decision making within the context of my research. Reed (2008) in a recent literature review on stakeholder participation for environmental management, states that *"the complex and dynamic nature of environmental problems requires flexible and transparent decision-making that embraces a diversity of knowledges and values. For this reason, stakeholder participation in environmental decision-making has been increasingly sought and embedded into national and international policy."* Whilst the focus on this thesis is sustainability the need to include stakeholder is repeatedly mentioned in relation to defining both sustainability and value (Tippett, 2004, Tippett, 2005, Meppem and Gill, 1998, Kaatz et al., 2005, Reed et al., 2006, Kaatz et al., 2006, Mills et al., 2006). This section considers stakeholder engagement in building design and compares this to the wider literature set.

Stakeholder engagement and participation is also now considered important in design as Newcombe (2003) argues that the concept of client, which has prevailed throughout the twentieth century, is now obsolete and is being replaced by the reality of project stakeholders. Subsequently, stakeholder mapping and engagement is now becoming increasingly important from many angles in the design of sustainable buildings, however this author argues that attention to this important aspect has not been given adequate consideration.

Freeman (1984) defines stakeholders as *"any group or individual who can affect or is affected by the achievement of the organisation's objectives."* In the design and construction of buildings this can encompass many groups, which span numerous organisations, from the project inception, design, construction, operation and finally demolition. Whilst there are many definitions of the term stakeholder, which vary in inclusiveness, there is wide spread agreement that there is a need for stakeholder support to create and sustain winning coalitions (Bryson, 2004). Given the wide number of actors typically involved in the design and construction of new built environments, it is therefore surprising that this has not been explored in more depth in the industry.

However, elsewhere, stakeholder theory has become a new narrative to understand and remedy three interconnected problems. These include the problem of: (1) understanding how value is created and traded; (2) connecting ethics and capitalism; (3) helping managers think about management so that the first two problems are addressed (Parmar et al., 2010). Parmar et al. (2010) in the paper titled, *'Stakeholder Theory: State of the Art'* suggest that whilst theory has developed significantly over the past 30 years, much territory is still unchartered. Areas they consider need further work are focused around the following (amongst many others):

- What does 'value' mean for a particular group of stakeholders?
- What are the key dimensions of each stakeholder relationships and how do we observe them? This includes generation of value creation possibilities, and degree of shared values and assumptions.
- Can we tell some interesting stories from the company and stakeholders' points of view?
- What are the industry best practices that illustrate stakeholder management? Can we build theory around these practices to show how and why they create value, specifically connecting purposes and values to specific practices?

Such issues are directly relevant to the project environment, especially in reference to problem (1), understanding how value is created and traded. This is becoming more discussed in the construction sector with industry reports such as the Egan Review (Egan, 1998) and others covered in Section 2.3.2 and authors such as Newcombe (2003) who argue that the client is typically a many headed creature. If this is the case, then understanding what represents value to the 'client' requires stakeholder engagement and analysis to capture the view of at least those that make up the client body. This section looks at methods and techniques engaging stakeholders and their success.

Reed (2008) provides a history and typologies of participation. The first considered the degree to which stakeholders were engaged (Arnstein, 1969). Arnstein (1969) developed a ladder of citizen participation, consisting of 8 levels which started at the passive dissemination of information, which she described as “manipulation”, to active engagement labelled “citizen control”. This has since been developed and also classified under different terms, which includes that widely used terminology of engagement as a relationship which can be “contractual”, “consultative”, “collaborative” and “collegiate” (Biggs, 1989, Reed, 2008). The ladder of participation has also been envisaged in different ways as the hierarchical natural of the ladder metaphor implies that higher rungs should be preferred over lower rungs (Reed, 2008), with some authors explicitly making this assumption (Arnstein, 1969). Davidson (1998) therefore suggested as an alternative metaphor the “wheel of participation”. This places an emphasis on the legitimacy of different degrees of engagement as appropriate for different contexts and objectives of the work and the capacity of stakeholders to influence outcomes.

Other means of categorising the type of stakeholder engagement have also been developed. Rowe and Frewer (2000) focus on the nature of the engagement, which considers both the process, along with ways of assessing what parts of the process ensure that it takes places in an effective manner; and acceptance, which is concerned with the features of the method that make it acceptable to the wider public. This identifies different types of engagement by the direction that information flows between parties.

There are numerous other types of categorisation that have emerged which are summarised in Reed (2008) and include normative and pragmatic classification. Normative focuses on the process and the democratic right that people have to participate in environmental decision making. The pragmatic argument focuses on engagement as a means to an end to deliver high quality decisions. This has also been classified as “political” vs “technical” participation (Thomas, 1993).

The final typology of stakeholder participation identified by Reed (2008) is based on the objectives for which participation is used.

Foo et al. (2011) outline that there are four different types of stakeholder engagement which local authorities conduct. This combines several typologies including that of Biggs (1989), Rowe and Frewer (2000) and typologies that consider the objectives for which participation is used (in considering the outcome) to categorise the type and quality of stakeholder engagement. Foo et al.'s (2011) method of classification is based on the role of stakeholders in the process and the outcome. Additionally the quality of such attempts can be judged in terms of process and satisfaction with outcomes (Leach et al., 2005). If stakeholders feel that their views and input have contributed to decisions and actions, they are more likely to be satisfied with the outcome of the engagement. Foo et al. (2011) summarised the four levels according to the quality of engagement as shown in Table 4—1.

Table 4—1 Quality and type of stakeholder engagement after Foo et al. (2011)

	Process		**Outcome**	
Level	Information and opinion flow from/to:	Strategy, method and timing design by:	Decision undertaken by:	Implementation undertaken by:
Communication	L > S	L	L	L
Consultation	L <> S	L	L	L
Consensus	L <> S	L	L & S	L
Collaboration/ Co-production	L <> S	L & S	L & S	L & S

Note: L = Local Authority; S = Stakeholders

In summary, these typologies of participation offer a way to understand the basis for stakeholder participation and can be used to select and tailor methods to the decision-making context, considering the objectives, type of participants and appropriate level of engagement (Reed, 2008).

There are few tools to which people undertaking stakeholder management activities can turn (Walker et al., 2008). This is problematic as these are typically soft skills which require both intuition and a strong skill for analysis. Walker, Bourne et al. (2008) also argue that high level conceptual approaches can benefit from allowing those involved to see clearly or to visualise the situation being examined. The techniques that are outlined in their paper are primarily about stakeholder identification and mapping the influence between stakeholders rather than those for visualising their thoughts and opinions.

Whilst, 'Exploring stakeholder needs and constraints to projects' is identified as the second most important of fifteen critical success factors for stakeholder management in construction according to research in the Honk Kong context (Yang et al., 2009, Yang et al., 2011b), none of the above steps include methods for actually eliciting what is important to stakeholders (i.e. their wants, needs and values) and for really identifying the project's context and capturing this knowledge.

Yang et al. (2011a) suggests a typology of 30 different approaches for stakeholder analysis and engagement informed by several studies. These approaches are also listed with which aspects of stakeholder management they are appropriate for (identification of stakeholders and their needs and interests; assessing stakeholder influence; analysing stakeholders' relationships; and stakeholder engagement) and the level of engagement (Inform, Consult, Involve, Collaborate, Empower). A summary of their strengths and weaknesses is also provided. Whilst, under the category of identifying stakeholders and their interests, tools such as focus groups, interviews and questionnaires and workshops are listed, these are considered fairly high level approaches. For example, no information is given on how workshops might be best structured to elicit stakeholder values, wants or needs.

Other techniques which have not traditionally been used with respect to defining the brief for sustainable building design and construction, but also offer potential in these areas include the work of Tippett (2004). Through her PhD, the DesignWays toolkit was developed which builds on several fields of sustainable planning including ideas and principles from The Natural Step, Permaculture, MindMapping, the creating thinking tools of Edward de Bono and Holistic Management (Tippett, 2005). This is discussed in more depth in Sections 2.2.2.3 and 4.2.

Emerging from this work was the Ketso kit; the approaches and workshop techniques can be seen on the Ketso website (Tippett, 2010). Ketso provides structure to the workshop and allows those involved to be engaged in the process to think creatively. It provides detailed structure on how to run an effective workshop, which is lacking in many stakeholder engagement examples. This includes facilitation plans and structures to workshop sessions which are considered very useful. The detail in the facilitation packs and the structure to workshops is something that is considered important in the development of techniques in this research. The researcher will explore the development of techniques for using with construction stakeholders in defining value and sustainability from their perspective.

Many of the areas for further work identified by Yang et al. (2011b) echo the work of Reed (2008). However, Reed (2008) whilst accepting that there is still much disagreement over what constitutes best practice, also identifies eight features of best practice participation that have emerged from a Grounded Theory Analysis of the literature. The features identified are as follows:

1. Stakeholder participation needs to be underpinned by a philosophy that emphasises empowerment, equity, trust and learning
2. Where relevant, stakeholder participation should be considered as early as possible and throughout the process
3. Relevant stakeholders need to be analysed and represented systematically
4. Clear objectives for the participatory process need to be agreed among stakeholders at the outset
5. Methods should be selected and tailored to the decision-making context, considering the objectives, type of participants and appropriate level of engagement
6. Highly skilled facilitation is essential
7. Local and scientific knowledge should be integrated
8. Participation needs to be institutionalised.

These provide a set of features against which stakeholder engagement/participation processes can be reviewed. Reed (2008) emphasises that the quality of decisions made through stakeholder participation is strongly dependant on the nature of the process leading them and it is the deficiencies in the process that are most commonly blamed for failures that lead to disillusionment in the process. Reed (2008) continues to explain that this arises from a focus on the tools of participation, rather than the process within which those tools are used.

van Asselt Marjolein and Rijkens-Klomp (2002) reflect on participation in Integrated Assessment from a methodological perspective. Integrated Assessment (IA) is defined as a *"research community explicitly focussing on research of complex issues and unstructured problems".* Whilst their paper is very much focused around stakeholder participation in research, many of their reflections and findings could also be considered appropriate with respect to stakeholder participation in sustainability decisions, as often there are parallel issues and unstructured problems. They define participatory methods as *"involvement in knowledge production and/or decision-making of those involved in, affected by, knowledgeable of, or having relevant expertise or experience on the issue at stake."* Their paper lists several participatory methods from the scholarly literature scattered over various disciplines. They also provide a framework for classification of the participation methods which considers the extent to which the participation method has a focus on the *"process as a goal"*, or the *"process as a means"*. For example, participatory methods are sometimes justified with reference to the nature of democracy where the participatory process is a goal in itself. At the other end of this scale is "participation as a means", to enrich assessment and decision-making through involvement of stakeholders in the process and subsequently a way to organise the decision-making process. These are two ends of the same axis, both dealing with the fundamental question of the weight and impact attached to the participatory process and its output.

The other axis of their two dimensional categorisation that van Asselt Marjolein and Rijkens-Klomp (2002) consider is the type of output that the participatory processes targets. This places "mapping out diversity" and "reaching consensus" at the opposite ends of an axis. Some methods focus on uncovering a spectrum of options and information and enabling groups to disclose a wide range of information and articulate tacit knowledge to test alternative strategies. Others focus on defining or singling out one perspective option or strategy to take forward. The former can be classified as approaches that are "mapping out diversity", whilst the latter can be characterised as "reaching consensus".

The techniques, reviewed from an extensive, but not necessarily comprehsensive literature review are shown in Figure 4—3.

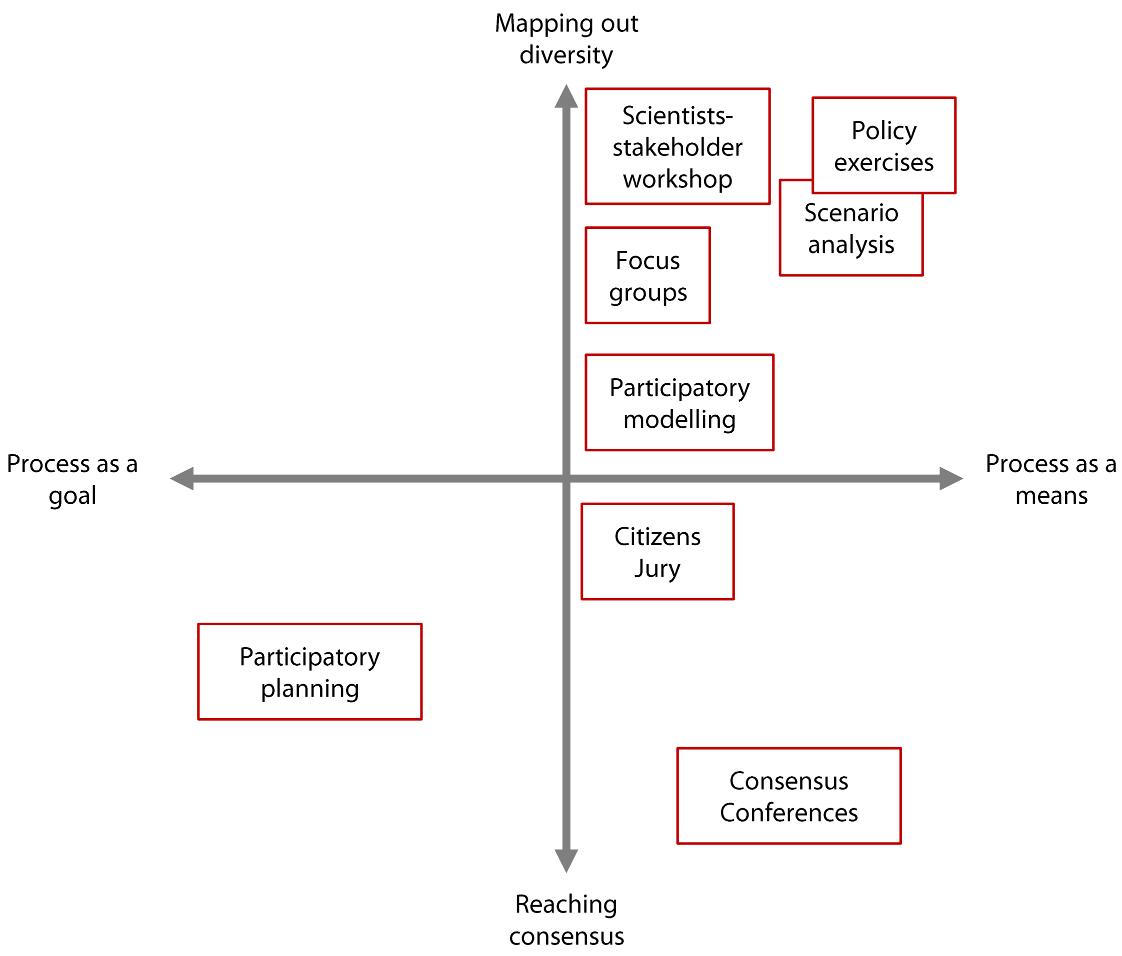


Figure 4—3 Typology of goals of participation after van Asselt Marjolein and Rijkens-Klomp (2002)

Their paper provides a summary for each of the above methods, which includes a description of the intended output, issues, key features of the process, associated tools and techniques of the process, intended participant numbers, participant type, duration and the focus of the task participants. Some of the methods outlined, overlap with tools and techniques that are considered systems approaches or problem structuring methods (PSMs), which are discussed in Section 4.3.2.

Stakeholder engagement techniques in the context of this research are intended to understand and structure the problem context in order to inform decision making. In this process, the focus is on understanding and accepting the diversity of stakeholder opinions before ultimately reaching a consensus of a particular action (or set of actions) to progress. The process is very much a means to better decision making with respect to sustainability rather than a goal in its own right. The next section will focus on problem structuring techniques that engage stakeholders to structure problems with the aim of informing decisions, with the stakeholder participation process as a means to achieving this.

The need for fast decisions on many client facing projects within the sponsoring organisation, means that collaboration is considered the most appropriate level of engagement with stakeholders, with an emphasis on the process being a means to gaining information on the project requirements from a sustainability perspective. Additionally, at the early stages, it is considered the process of stakeholder engagement is not particularly focused on either end of the diversity/consensus spectrum as detailed in Figure 4—3. The focus is around structuring the problem with an emphasis on defining sustainability and value objectives to inform decision making. Therefore, the next section considers problem structuring methods and their suitability as processes for engaging stakeholders to better understand and structure a problem.

4.3.2 Problem structuring methods

Whilst sustainability is a complex issue, which requires understanding the interaction and integration of human, economic and ecological systems, there are many other complex systems that require problem resolution. Therefore, this section considers some of the approaches that have emerged from other areas of the literature, such as operational research and decision making. The intention is to distil some of the principles from such approaches and understand whether they may be useful in the context of this research.

“Most operational researchers agree that structuring a problem – taking it from an initially vague and ill-defined problem to one that can be formulated, modelled and analysed mathematically – is the hardest yet most crucial part of an operational research analysis. This is certainly true in decision analysis, where the emphasis of problem structuring is on shaping some general statements by decision makers and stakeholders about their goals, concerns, issues, and uncertainties and turning these statements into a clear and transparent representation of the decision problems which can be mathematically formalised using principles of decision theory.” (von Winterfeldt and Fasolo, 2009)

PSMs focus on structuring messy ill-defined problems (e.g. complex human systems coupled or interacting with natural systems) as opposed to solving well-structured problems with mechanistic approaches (Mendoza and Prabhu, 2006). For messy and unstructured problems, Problem Structuring Methods (PSMs) are considered appropriate decision support tools (Franco et al., 2004, Mingers, 2000, Mingers and Rosenhead, 2004). They are considered by this author to fall under the subset of stakeholder participation and engagement techniques, with a focus on also building models of the problem situation.

Problem structuring according to Khadka et al. (2013) is involved with problem identification and modelling as opposed to problem solving.

Rosenhead and Mingers (2001) explain how planning and managing the real world is engulfed in uncertainty, knowledge is incomplete, values in dispute, decisions are often unpredictable. Mathematical models that are sheathed in opaque technicalities, inflexible and over-ambitious methods of analysing problem situations are no longer considered acceptable. Techniques were therefore required that could be applied to ill-structured problems and it is in this area that problem structuring methods (PSMs) are required. PSMs, also known as soft operational research (OR) methods, focus on human and political aspects of problems (Mingers, 2000).

Problem structuring methods address such problems and emerged from practice in parallel with an extended critique of traditional operational research, which was increasingly considered to be restricted to well-structured problems, where formulation can be stated in terms of performance measures or measures, constraints and the relations through which action produces consequences (Mingers and Rosenhead, 2004). PSMs were only theorised and systematised at later stages (Mingers and Rosenhead, 2004).

PSMs address problems that are characterised by the existence of multiple actors, multiple perspectives, incommensurable and/or conflicting interests, important intangibles and key uncertainties. Such characteristics relate to many issues discussed when trying to define sustainability and implement sustainable development from a pragmatic realist perspective. Additionally, there is significant overlap with some of the techniques outlined with respect to stakeholder engagement and participation as all PSM techniques discussed below involve interaction with stakeholders. Therefore this section of the literature review has the intention to distil some of the principles from PSM approaches and understand how they may be useful in the context of this research.

All PSMs share the ability to model the problem situation so that the people involved are clearer about the issues at stake, and can converge on, or commit to a potentially actionable set of priorities (von Winterfeldt and Fasolo, 2009). Many of these approaches are also categorised as ‘system thinking’ approaches, which aim to think holistically about the issues. Numerous systems thinking approaches are summarised and critiqued in books (Jackson, 2000, Jackson, 2003, Flood, 1999). Jackson (2000) provides a framework for categorising such systems thinking approaches, according to the problem context that they are most suited. This categorises the problem context in two dimensions, which are the complexity of the system and the divergence of perspectives among potential participants. Problem structuring techniques can be considered to be in the pluralist area of his categorisation, addressing both simple and complex systems.

Khadka et al. (2013) split problem structuring into formal methods, and other methods that may be used in problem structuring as well as problem structuring action types which include, brainstorming / brain writing, static-system modelling, dynamic system modelling, role plays. They reviewed 32 case studies of participatory forest planning or forest management decision making with direct communication between stakeholders. The most popular participant types were “Government authorities and local people”. Private sector was the least frequently engaged stakeholder groups as categorised by the research. Of the practical methods, brainstorming / brain writing was the most popular practical method, followed by dynamic systems modelling, followed by static system modelling and finally role play. Typically they were more applied in less industrialised countries.

Khadka et al. (2013) concluded from their review that PSMs and wider problem structuring action may help utilise and combine the local, historical and culturally grounded practical knowledge with the expertise of resource managers and professionals. Even though there were several examples of problem structuring being used, they state that it had rarely been used in a sophisticated manner in the forest planning context, however a few good examples existed and PSMs and related facilitated modelling paradigm are recommendable. Smooth facilitation as well as the presence of conceptual modelling expertise is worth paying attention to. Before interpreting problem structuring processes as too promising accelerators of social learning, one has to critically note that earlier research has distinguished only single loop learning in natural resource governance processes. This is therefore identified as an area for further research.

Franco and Montibeller (2010) consider the facilitated modelling as an intervention tool and provide a general framework to conceptualise a wide variety of approaches to organisational interventions. Design issues in facilitated modelling and their practical implications are discussed, and directions for future research identified. This is therefore considered an alternative term for problem structuring methods which require the same combination of facilitation and modelling. They develop Figure 4—4.

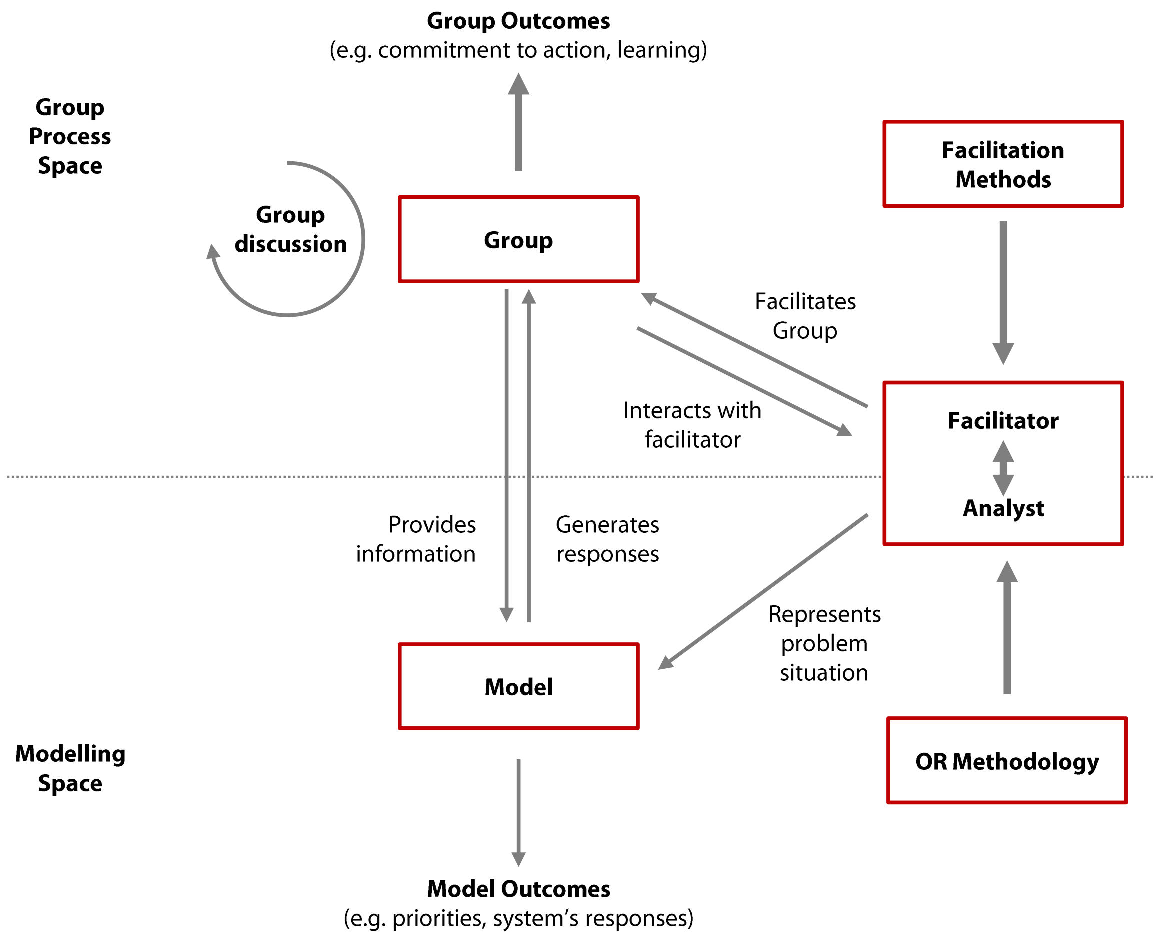


Figure 4—4 Facilitated modelling in operational research after Franco and Montibeller (2010)

Franco and Montibeller (2010) consider 6 design issues that require consideration in practice. These include (1) the focus of the modelling, (2) the type of data gathering for structuring the model, (3) the type of data requirements, (4) the degree of technology support required, (5) the degree of flexibility of modelling rules, and (6) the degree of content facilitation required. These are considered useful aspects to consider in problem structuring methodologies. However, it should be noted that when considering facilitated modelling, they are doing so with respect to a single facilitated modelling session delivered in a 1 to 3 day workshop. This is unlikely to be possible in the context of building design.

Whilst different authors classify different techniques under the broad remit of PSMs and ‘softer’ methods (Mingers and Rosenhead, 2004, Jackson, 2003), the following sections reviews 5 different PSMs that offer potential to structure the problem context with respect to sustainable building design. Some common PSM approaches are explained in the following sections.

4.3.2.1 Interactive Planning

Interactive planning is focused in systems thinking and is “based on the belief that an organisations future depends at least as much on what it does between now and then, as to what is done to it” The method therefore focuses on creating the future by designing a desirable present. Then continuously closing the gap between the current and desirable state, involving the organisation’s stakeholders in the planning process. This process can be split into two distinct parts which are *idealisation* and *realisation*. These parts are divisible into 6 stages. The parts and stages are summarised below based on Ackoff (2001).

Idealisation initially focuses on (1) “formulating the mess”. That is understanding and learning about the current state of an organisation and then setting up a “reference projection” which is based on the assumption that there will be no change in the organisation’s behaviour and that the relevant future predicted by the organisation is complete and correct. End’s planning (2) then focuses on defining the desired present state and identifying gaps between this and the future state. The second part, “realisation” then considers (3) *“means planning”* which considers the means of reducing the gap between the reference projection and the desired current state; (4) *“resource planning”* what is required to bridge the gap; (5) *“design of implementation”* which considers who is to do what, when and where; and (6) the *“design of controls”* to monitor assignments and schedules.

This methodology is focused more around organisational change rather than the design of tangible artefacts such as components of the built environment. Additionally, it is described as a continuous process, whereas this research is focus on making sustainability decisions in the design process that will deliver constructed assets. These decisions are likely to be long lived and small adjustments after a certain decision are not possible in the context of this work. However, elements of the “idealisation” process such as defining the current situation and the desired situation could provide criteria on which to base such decisions. Additionally the approach actively engages stakeholders, which again points to the need for stakeholder participation in dealing with complex and “messy” problems.

4.3.2.2 Soft Systems Methodology

Soft Systems Methodology (SSM) is a problem-solving framework designed specifically for situations in which the nature of the problem is difficult to define (Sinn, 1998). The methodology allows participants to explore different ways of viewing a problematic situation. The active participation of stakeholders is essential as it seeks to compare different “world views” referred to as weltanshauung. The process consists of seven stages, however Checkland and Scholes (1990) emphasise that these stages merely provide a guide to the types of thinking that should be occurring and do not need to be followed sequentially. The 7 stage process is as follows:

1. Enter the problem situation
2. Express the problem situation
3. Formulate root definitions of relevant systems
4. Building conceptual models of human activity systems
5. Comparing the models with the real world
6. Defining changes that are desirable and feasible
7. Taking action to improve the real world situation

Through multiple iterations of the process, it is intended that stakeholders (clients – beneficiaries or victims of the system, actors – those responsible for implementing the system, and owners – those with the authority to change the system or its performance measures) engage in debate guided by a facilitator. This repeats until a model is achieved by consensus and this forms the basis for development.

Again this is aimed at organisational problems and is somewhat difficult to relate to the building design and construction process. Like interactive planning, there is an element of comparing the problem situation, to the desired situation and defining changes to be made. However, this is again a very qualitative approach, and in the case of selecting building and in particular roof systems, the technical performance of the different systems is likely to be extremely important in defining which “action” to take forward. Therefore, a way of incorporating quantitative performance is considered necessary.

4.3.2.3 Strategic Assumption Surfacing and Testing (SAST)

SAST (Mason and Mitroff, 1981) is a methodology based on four principles which are participative, adversarial, integrative, managerial mind supporting. This is based on the belief that different stakeholders should be involved, and that different stakeholder perceive wicked problems differently and that judgements about how to tackle such problems are best made after full consideration of opposing perspectives (Jackson, 2003). The different perspectives are acknowledge and the methodology is based on the approach that different options from opposing perspectives must eventually be brought together into an action plan. The approach allows different perspectives to surface and develops the thoughts of managers (managerial mind supporting) through exposing different assumptions that highlight the complex nature of wicked problems. This includes a tool to rank each of the assumptions on which a strategy is based according to two dimensions which are, (1) how important the assumptions are, and (2) how certain the assumptions are.

It is argued that SAST is aimed at situations where the strategies for possible solutions rest on assumptions which are in conflict with one another. However, in the case of this work, it is intended, that no potential solutions or strategies will have been developed, when considering the objectives of the project and the objectives on which roof decision could be made. Therefore this method was not considered appropriate in the context of this research.

4.3.2.4 Group Model Building

Group model building, is a variant of systems dynamics modelling with an emphasis on messy problems (Vennix, 1999). Vennix et al. (1992) surveyed the existing literature on mapping and eliciting knowledge for system dynamics modelling and also explored the literature in the broader fields of cognitive psychology and small group processes. He showed how these knowledge-eliciting techniques can be used to support the construction of computer simulation models. In this paper he discusses the stages and steps in model building and what techniques and the suitability of different techniques for incorporating different types of knowledge at different stages of the process. Through a review he identifies factors that help the modeller structuring the knowledge elicitation process. These include (1) the phase of the modelling process and type of task, (2) the purpose of the modelling effort, (3) The number of people, (4) the time available for participant discussion, and (5) the cost. However, Vennix et al. (1992) state that the recommendations are tentative and how to combine the factors in selecting appropriate knowledge elicitation techniques remains more of an art than a science.

More recent work (Rouwette et al., 2002), reviews the effectiveness of group model building and considers the outcomes from the perspective of, insight, commitment, behaviour, communication, consensus, system changes and results. As well as considering the context with respect. They also note the context, which fits into, demonstration/training, conflict/intangible/data-rich/tangible along with the number of studies reviewed and the typical number of participants and time required for the process. This ranged from 4 sessions of 2-3 hours for training on group model building to year-long continuous studies. In the context of building projects, it is considered that access to the stakeholder group will be limited and the entire project timeframe can be extremely quick in comparison to these time frames. Thus extended periods of engagement are unlikely to be possible. Consideration of an approach which is relatively simple and quick to undertake is therefore imperative.

4.3.2.5 Strategic options development and analysis (SODA)

SODA (Eden and Ackermann, 2001) is a technique to help someone understand the various viewpoints of a problem area. The process involves planning meetings to set up and gain an initial view of a problem and understand who the participants will be and the outputs they expect. This is followed by client interviews which are used to explore individuals' views of the problem area/situation. Then causal maps are used to visualise the interviewees perceptions of the situation. These are presented back to interviewees to check that they represent their views. The maps are then merged and presented to the participants and worked on until everyone finds them acceptable. The maps are then used to interpret the map in terms of the goals, strategies and tactics and allocated to people for implementation.

Unfortunately, in the context of this research, there is unlikely to be time for numerous client interviews to explore individual views of the problem situation as well as opportunities for numerous engagement sessions with the client and stakeholders of the project. However, with respect to the problems of this research, the causal mapping process does have some merit at looking at the relationships between various statements and in the case of this research the objectives for decisions.

4.3.2.6 Problem structuring methods in the context of sustainability assessment and decision making

PSMs have been applied significantly in other fields such as forest planning. A paper by Khadka et al. (2013) titled “problem structuring in participatory forest planning” undertook a structured literature review of the use of problem structuring in this context. This identified a range of the most prevalent positive effects and critical aspects of problem structuring that were recognised in the reviewed participator forest planning cases which included, meaningful learning, evoked interest, commitment to the process and improved knowledge exchange.

For example, in forest planning, Khadka (2013) undertook an analysis of problem structuring activity within participatory forest planning over the period from 2002-2011. A total of 32 articles were studied. They found that only 5 of the 32 studies dealt with a small area (less than 2000 hectares), with most of the PSMs being in Asia and Africa. Only 13 of the 32 studied applied PSMs in full and referenced established methodologies as referenced in Mingers and Rosenhead (2004). The types of participants involved in the studies showed Governments and local people being in 26 of the studies, scientists in 23, NGOs in 18 and Private sector companies in just 10 of the 32. They conclude that *“PSMs and wider problem structuring action may help utilise and combine the local, historically and culturally grounded practical knowledge with expertise of resource managers and professionals”* but it has not generally been used in a sophisticated manner. They stress the need for smooth facilitation and presence of conceptual modelling expertise. Finally, they stress that scientific literature gives little evidence of the long-term effects and provides scarce ex-post evaluation of PSM and wider problem structuring applications. Further work is therefore around employing surveys to understand the impact of problem structuring processes and focus on actual group interactions through action research.

von Geibler et al. (2010) developed indicator sets for the sustainability assessment of entire value chains of forests. Of particular note, is that they integrate indicators defined by stakeholders, experts, and also from the literature into their indicator set and in doing so consider the integration of the cultural and natural system and interaction between the two system types. Integration of stakeholder and expert opinion was done through transcribed interviews with 16 people in the specific case study of the value chain "construction and refurbishment with wood" . They also integrated the indicator set into a decision support tool, which involved semi-qualitative self-assessment of the environmental, social and economic aspects of sustainability. This considers the target users' low awareness and knowledge on the subject of sustainability. They conclude that the output was novel, additionally, the combination of life cycle assessment approaches and system wide approaches considering different value systems that move beyond discipline boundaries is necessary to promote change towards sustainability in complex socio-ecological systems.

Souza et al. (2014) have recently looked at problem structuring methods as a way of defining sustainability impact categories based on stakeholder perspectives. They discuss that the selection of social criteria and their quantification is still one of the major challenges, and that interested parties should be involved in order to better define the decision context and the purpose of the study but in practice Sala et al (2012) c.f. Souza et al. (2014), they look to combine PSMs, which they explain as eliciting and structuring stakeholder perspectives as a support for decision making and defining strategic objectives, operational objectives all the way down to potential alternatives in a means ends structure as based on Keeney (1996). They describe the use of causal maps, a method used in SODA, to select LCA impact categories to inform decision making with respect to a waste electric and electronic equipment reverse logistics systems in Brazil.

Souza et al. (2014) discuss the issues of the implementation of the methodology, one of which is applying the methodology comparatively. They explain how while applying the methodology is in principle context –free, the data it elicits from stakeholders is not. Therefore it will not provide a standard set of indicators, which in turn will be dependent on context. They do conclude however that the mixture of methodologies make a useful contribution to structuring and selecting social and economic impact categories based on real stakeholders' perspectives.

Hector et al. (2009) developed a problem structuring technique, which is based on philosophical and psychological dimensions which are explicitly stated and explained. They test the methodology in the context of developing a sustainable water system for Sydney. However, whilst stating the usefulness of the approach, there was seemingly no attempt to get feedback from participants. Additionally, the number of workshops required or time taken to apply was not stated in the paper and after several engagement sessions, no clear objectives for the system on which a MCDA could potentially be applied had emerged.

However, increasingly PSMs are being used in combination with decision analysis (von Winterfeldt and Fasolo, 2009). For example, Neves et al. (2009) utilise soft systems methodology to structure a multi-criteria decision analysis model. This involved using SSM to elicit the most important concerns regarding energy efficiency measures and also developing a “cloud of objectives” that each potential evaluator of energy efficiency measures may pursue. Feedback was that SSM was very helpful in this exploratory stage. SSM and VFT were therefore successfully used in sequence. However, the “value-focussing” was already present during the SSM and is thus richer than simple sequence. Follow up interviews, gave confidence in the completeness of the model.

4.3.3 Summary of problem structuring methods

Problem structuring methods are softer more qualitative techniques aimed for use with a group of people to better understand the problem situation and help to co-design potential actions and solutions. With complex concepts such as sustainability and value, they potentially have merit in being able to define and structure the objectives for decision making. However, of the PSMs reviewed, it is not considered that any of them in isolation is suitable for use in the context of construction. Most papers reviewed, detail how the above PSMs are used iteratively over numerous and often long workshop sessions with a number of stakeholders. Through the experience of the author working in the construction industry, along with the literature review detailing the fast paced nature of design of buildings, it is considered that they would be too time consuming to apply in full. Additionally, with respect to the quantification of performance of options and the desire to develop a system that can rank alternatives it is considered that they are inadequate in their own right. Additionally, examples of their application have generally been at an organisational level, or in defining broad policies, and in doing so being used at a significantly large scale than the consideration of buildings. In Rosenhead (1989) there is discussion on numerous PSMs, which include SSM, SODA amongst other techniques. With respect to SSM there is much discussion about how it is best used where there is no common agreement on what constitutes the problem itself. SODA, is also a technique that is intended to help people develop a mutual problem definition. In the context of this research, the problem to some extent is relatively well defined: what roof system should we select? However, the objectives of the decision are not always clear. VFT offers an approach for developing these and also considering the relationship between strategic objectives, specific lower level decisions and the evaluation of options.

In the Lim (1991) review of Rosenhead (1989), explains that there are also some limitations of PSMs that are little discussed in book including the substantial time and effort requirement to implement these methods. Considering this within the challenges of the design process, the time required to implement techniques is a critical issue. Another problem Lim (1991) identifies is that these methods does not absolve decision makers from making non-rational decisions. The usefulness of these methods depends in part on the accuracy of the participants’ perceptions. Lim’s final criticism includes that the book downplays the quantitative aspects of decision structuring aids with little empirical research focusing on the effectiveness of the PSMs discussed.

In the case of this research, the focus is more concerned with the elicitation of objectives rather than defining the problem, which aligns with the VFT approach of Keeney (1992) (see Section 4.5).

However, many of the facilitation tools included in PSMs are considered potentially useful, and where considered appropriate by the researcher and fellow practitioners have been considered in the development of workshop techniques for implementation.

Additionally, there has been a recent move in the literature at the potential of mixed methods, where softer problem structuring techniques such as those described above are combined with hard techniques such as MCDA in complementary ways.

As this research aims to address some of the weaknesses of current environmental assessment methods (see Section 2.3.1.7) techniques included in PSMs are considered appropriate as approaches at aiding many of these considerations. Such techniques could help structure the problem into a set of objectives on which more quantitative approaches, such as multi-criteria decision analysis (MCDA) can be applied. The next section considers approaches for the evaluation of options through MCDA techniques.

4.4 Evaluation of options

Within the context of sustainability and value, design options require assessing across multiple objectives and can be classed as complex decisions. Indicators can help assess the performance of designs and help inform decision making, however they are not typically decision making tools in their own right. Therefore, this section briefly reviews some of the decision making techniques that are generally considered useful in helping to analyse complex problems with multiple objectives. This section draws heavily on books by Goodwin and Wright (2009), Clemen (1996) and Keen and Morton (1978). First, the advantages of undertaking a formal and structured decision approach are outlined based on points made in Goodwin and Wright (2009).

Psychologists have shown that the human mind has cognitive limitations and tend to use approximate methods to deal with decision problems without having a formal decision analysis method. This is referred to as 'bounded rationality' (Simon, 1982). Research shows that such methods often seek satisfactory decisions rather than optimal courses of action. Such approximate methods are often termed heuristics. These are intuitive techniques that most people will typically utilise in order to make decisions in the absence of decision analysis. Heuristics are well adapted to particular tasks, for example where quick decisions involving little mental effort are required (Girgerenzer et al., 1999). However, in decisions involving multiple objectives, decision makers using such heuristics tend to not make trade-offs by accepting poorer performance on some attributes in exchange for better performance on others. In other words the simple heuristics are often not compensatory due to the limited amount of information that humans can process at a given time. This may mean that unaided decision makers may reject relatively good options because their good performance across a range of objectives is not allowed to compensate for their poor performance in other areas. Decision analysis therefore provides a structured way of assessing options. It encourages exploration of trade-offs between attributes and the assessment of the performance of options based on a set of axioms. It also encourages decision makers to challenge their perception of risk and uncertainty. Finally, it provides an audit process for decision making showing the rationale for selecting a particular option.

As has been described to make well informed decisions a framework capable of incorporating hard data with soft opinions is important. A multi-criteria decision analysis (MCDA) may therefore be an appropriate framework as it possesses the following advantages (Department for Communities and Local Government, 2009):

- *"it is open and explicit.*
- *the choice of objectives and criteria that any decision making group may make are open to analysis and to change if they are felt to be inappropriate.*
- *scores and weights, when used, are also explicit and are developed according to established techniques. They can also be cross-referenced to other sources of information on relative values, and amended if necessary.*
- *performance measurement can be sub-contracted to experts, so need not necessarily be left in the hands of the decision making body itself.*
- *it can provide an important means of communication, within the decision making body and sometimes, later, between that body and the wider community, and*
- *scores and weights are used, it provides an audit trail."*

Additionally, research which considers multiple criteria analysis and unaided approaches to environmental decision making shows that decision makers perceive the multi-criteria analysis improves the decision process through better learning, clarification, transparency and accountability (Hajkowicz, 2007).

Other review papers have applied a multi-criteria decision analysis in natural resource management (Mendoza and Martins 2006). It should be noted that their study wasn't focused explicitly on sustainability. They state that MCDA has inherent properties that make it appealing and practically useful as it (1) seeks to take explicit account of multiple, conflicting criteria, (2) it helps structure the management problem, (3) it provides a model that can serve as a focus for discussion, and (4) it offers a process that leads to rational, justifiable, and explainable decisions. They review MCDA techniques based on the problem that they were employed to address, categorised by (1) the nature and context of the problem, (2) type and complexity of the method; (3) number and type of decision makers. They conclude that MCDA techniques can have limitations due to their inability to deal with problems, where the objectives might be neither clearly stated nor accepted by all constituents, with unknown problem components, and with unpredictable cause-and effect relationships. They conclude that a transparent and participatory approach to the definition of planning and decision problems would also be desirable and detail that soft systems approaches are useful to structure wicked, messy, ill structured or difficult to define problems. It is stressed that this is not to devalue MCDA methods, but the integration of a qualitative approach to problem structuring, with the structured approach of MCDA to retain some of the analytical capabilities of the hard systems approach, is one of the key aspects of the integrated approach they suggest; detailing how this integrated approach allows one to embrace the strengths of each method. They are therefore advocating, in the opinion of this author, a pragmatic realist approach. This is supported by Mingers (2000) who offers a compelling argument to combine soft and hard systems methods, advancing the idea of mixing methodologies.

General review articles of multi-criteria decision making in environmental decision making indicate that multi-criteria decision support has been undertaken in a range of contexts (Kiker et al., 2005). However, the review covers numerous papers generally at a large scale .These include water use planning, watershed management, forestry management, energy policies, emergency management of nuclear accidents, etc. However, they conclude that few studies use MCDA techniques to engage stakeholders and that most studies represent the value judgements of a single stakeholder. Other stakeholder values are often considered as an additional attribute. Kiker et al., (2005) synthesise the decision making concepts stating that successful environmental decision making will depend on the extent to which three key components are integrated. These include (1) people, (2) process, and (3) tools.

This work essentially seeks to build on the work of others, which has typically been undertaken at a larger scale and is currently recognising the need to combine both soft modelling techniques of problem structuring methods and also hard techniques such as MCDA in order to make more informed decisions. However, this research focuses on the smaller scale application of such techniques in the building project environment. This context is significantly different to many of the papers reviewed in forestry (Mendoza and Martins 2006) and general environmental decision making (Kiker et al. 2005). Thus an action research based approach to this research within the context of building design is considered an appropriate way to progress. Working with practitioners to develop methods suitable for application in the construction process with respect to the definition of sustainability and then the selection of more sustainable roof systems.

The next section discusses the value focused thinking approach developed by Ralph Keeney, as it considers both the definition of objectives for decisions based on values, in order to be able to undertake quantitative based analysis. Therefore, it is considered that such an approach provides a possible way of combining technical performance data with softer opinions on what represents value for stakeholders and thus provides a coherent approach of going from unstructured objectives to quantified analysis.

4.5 Value focused thinking

This section draws heavily on the work of Ralph Keeney and his book entitled 'Value-Focused Thinking' (Keeney, 1992), a technique considered to offer the philosophy on which the decision making framework in this research is based. He takes a stakeholder driven, values based approach, which seems particularly applicable to the problem context of this work. It is discussed as value focused thinking provides a method of combining softer techniques aimed at understanding values and defining objectives, and relating these to objectives on which to base decisions.

Keeney (1988) states that within any decision problem, the intent is to select the best alternative from those already available or to create alternatives better than those already apparent. The concepts of best and better are based upon preferences or values. Keeney uses these terms synonymously. They provide a general road map to decision making processes. Without these, he claims that there is no reason to be concerned about which alternatives should be chosen. These values he claims are more fundamental to the decision problem than alternatives, which are just a means to achieving those values. Keeney (1992) encapsulates this by saying that, *"the standard way of thinking about problems is backwards... people focus first on identifying alternatives rather than articulating values."*

Keeney criticises alternative-focused thinking saying that problems with this approach are that values should provide the guidance for all the effort on a problem, and yet they are usually treated cursorily and considered only after the set of alternatives is known. The process of identifying alternatives often consists of just choosing those readily apparent. The interaction between values and the creation of alternatives receives essentially no attention. Almost all the effort is reserved for a partial evaluation of the given alternatives. It is partial because the set of objectives is not complete, the criteria (or measures) do not reflect the fundamental objectives but rather proxies and the achievement of different objectives (or proxies) is not integrated. Invariably, existing methodologies are applied to decision problems once they are structured, meaning after the alternatives and objectives are specified. Such methodologies are not very helpful for the ill-defined decision problems where one is in a major quandary about what to do or even what can possibly be done.

Value focused thinking is different in that it involves initially focusing early and deeply on values when facing difficult problems. His premise is that this will lead to more desirable consequences, and even to more appealing problems than the ones we currently face. In short, we should spend more of our decision making time concentrating on what is important: articulating and understanding our values and using these values to select meaningful decisions to ponder, to create better alternatives than those already identified, and to evaluate more carefully the desirability of the alternatives. *"Value-focused thinking essentially consists of two activities: first deciding what you want and then figuring out how to get it,"* (Keeney 1992).

He describes value focused thinking as a philosophical approach providing a methodological help to understand and articulate values, which can be used to identify decision opportunities and to create alternatives. Keeney (1992) (p22) explains that decisions which are real, important and complex with no clear 'solution' are ideal for value-focused thinking. Therefore, within the context of sustainability, value focused thinking appears to be suitable.

First, value focused thinking involves thinking hard about your values, not alternatives. He describes, values as the principles used to evaluate the *"actual or potential consequences of action and inaction, of proposed alternatives, and of decisions. They range from ethical principles that must be upheld to guidelines for preferences among choices." In doing this you should a*sk what you hope to achieve in the decision context you face. Write down a list of your responses. Then push yourself to think of anything else that should be on the list. Once you have a list, scrutinise each of these carefully. Ask why each objective is important. The responses will probably add objectives to your list. Once you feel the list of objectives is reasonably complete it is important to specify clearly what each objective includes. The general principle of thinking about values is to discover the reasoning for each objective and how it relates to other objectives.

In working with groups and engaging stakeholders, Keeney explains that values are what should be discussed when people talk about the pros and cons of alternatives. He explains that in public problems, *'values, rather than facts are the aspect of the problem about which many members of society will have knowledgeable viewpoints.'* Discussion of the details of the consequences of various alternatives often depends on technical and complex concepts from various professional fields. Hence, without discussion of values, many people are excluded from participation and others are limited to minor contributions.' (P25). Therefore it is values that broadly open up stakeholder engagement to be inclusive and to define what they are trying to achieve.

Value focused thinking has been used in many contexts. Ewing and Baker (2009) utilised a collaborative process to develop a green building decision support tool utilising the principles of value focused thinking and multi-objective decision analysis. The value focused thinking was used with the group of stakeholders to define the key evaluation criteria for the decision, which included environmental impact, educational effectiveness and financial costs. The group of students then developed a set of alternatives to consider in the decision process, along with measures to assess performance in relation to the key evaluation criteria.

The outcome was the production of a tool (an excel based spreadsheet) which included stakeholder input into the environmental valuation of the performance of different options. This involved converting all aspects of environmental performance into monetary terms. This was informed through a literature review looking at what financial costs ($) various authors put on aspects such as tonnes of CO_2 emitted and educational value. The best option was then the one with the lowest preferred adjusted cost. The approach did not really comment on the success of the application of value focused thinking. However, they conclude that the process overall had educational value for the students involved and was able to find the lowest cost alternative set.

In McDaniels (1994) value focused thinking is used to understand value trade-offs in electric utility planning. McDaniels' justifies the use of the value focused thinking approach by stating the need for direct consideration of value trade-offs amongst fundamental social and environmental objectives, as a basis for selecting alternative courses of action regarding sustainability issues.

Whilst the approaches used were a relatively simplistic form of multi-attribute approaches, where no quantitative value functions were defined, two key concepts were illustrated. The first is that by clarifying the interests of stakeholders, with even limited information, it may be possible to create strategies that could potentially achieve wider support in complex environmental conflicts. The second shows that the steps involved can provide what is needed to gain insight in a given decision context. They conclude that real progress on collective environmental choices will require greater insight into the trade-offs among conflicting environmental and economic objectives, as seen from the viewpoint of relevant stakeholder groups and argue that value focused thinking is one way of considering this.

Additionally, McDaniels et al. (1999) explain that value based approaches result in a higher level of comfort for participants and are useful in developing consensus-based management decisions. They conclude that successful environmental decision making in complex settings will depend on the extent to which people, process and tools are integrated.

Merrick and Garcia (2004) applied Value Focused thinking to evaluate the condition of a watershed and prioritise improvement initiatives. This involved building a multi-objective decision analysis model and utilising it to assess the health of water in Richmond, Virginia. They used the approach to compare a hypothetical, perfect watershed. Weighting the value gaps, then became a method to understand which particular aspects of the watershed are most impaired and where the greatest improvements could be made. They conclude that the approach was successful in providing an integrated watershed assessment for the interdisciplinary team and integrating environmental, social and economic objectives into selecting a course of action. In using the approach with different sets of values, planners and decision makers could see the impacts that the values have on the selection of different strategies for management and consider associated trade-offs.

McCourt (2007) used value focused thinking to look at the selection of energy efficient low slope roofing technologies and was found to be effective in the context of the US military. Due to the relevance of this work to this research this was reviewed in more depth in Section 3.7.3. However, on the whole, value-focused thinking was found to be a useful tool in selecting energy-efficient roofing technologies. This work aims to address some of the limitations of the approach, such as a focus on a limited number of criteria, with no explicit process for modelling or considering the latest literature in assessing the performance of different roof systems. Additionally, there was very little with respect to linking roof objectives to project objectives and stakeholder values and sustainability considerations.

Critiques on the value-focused thinking approach outlined in Keeney's book include a lack of consideration of beliefs and uncertainty in the approach, however it is clear that this is not forgotten in the examples included in the book (French, 1993). He also does not discuss the organisational context of decision making. However, it could be argued that these are not considered in this book because much of the decision analysis literature covers such aspects.

However, where value-focused thinking is differentiated from other problem structuring methods is it provides an approach that goes from structuring the decision through considering values to structuring objectives and assessing options quantitatively and utilising the outputs to inform group dialogue and negotiate ways forward. The concept of value focused thinking is therefore considered an appropriate starting point for this research and ways which can inform the dialogue between stakeholders and help define stakeholder values in the project environment. This essentially helps provide further structure to Keeney's phrase, *"think hard about your values"*.

However, this research wishes to build on Keeney's approach to structuring objectives through considering different approaches to understanding stakeholders' values for projects. It is intended that these will complement the overall value focused thinking approach in the context of sustainability and construction projects.

Another reason for utilising VFT was it was considered that it would be difficult to engage non-technical stakeholders of a building project with respect to solely the roof decision. Additionally, if argued that this was required for decisions with respect to roofs, then it could be argued that a similar engagement process should be undertaken for facades, building services systems and all other building related decisions that impacted on stakeholders. Therefore, it was considered that thinking about the fundamental strategic objectives for the project rather than the fundamental objectives for just roofs was at the appropriate level of abstraction to engage stakeholders. Essentially, the value focused thinking approach provided a theoretical underpinning for doing this.

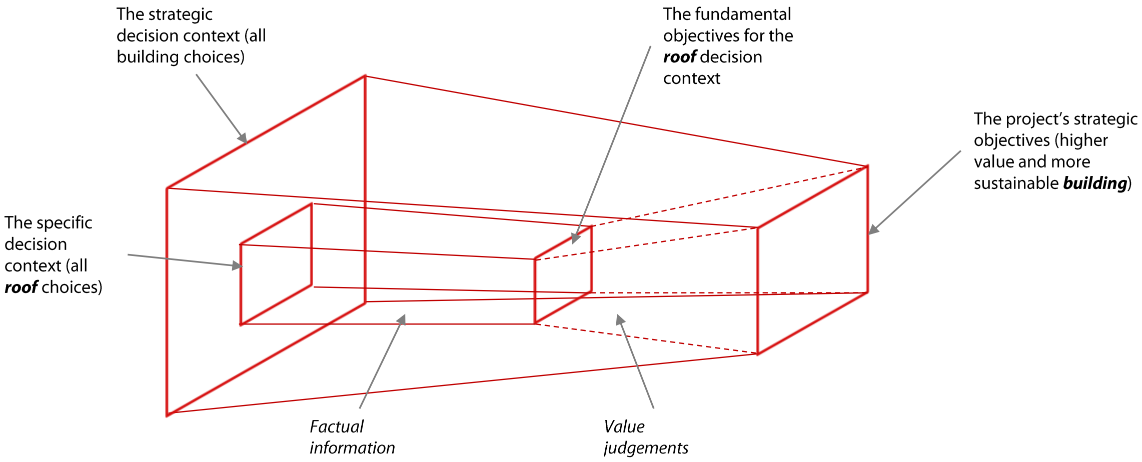


Figure 4—5 The value focused thinking framework as applied to roofs

Figure 4—5 shows the value-focused thinking framework for a specific decision within the framework of a decision maker's strategic decision context. This is framed by the decision context on the left and the strategic objectives on the right. The small box inside the larger one represents the specific decision situation (in the case of this research this is related to selecting sustainable roofs). The strategic decision context is much larger than the specific decision context, as there are significantly more building alternatives than roof alternatives (the roof represents only a subset of choices for the overall building project).

Factual information links the performance of alternatives to the fundamental objectives for the roof decision context. However, the fundamental objectives for the roof decision context, should align with the project's strategic objectives. It therefore provides a way of considering problem structuring and quantitative decision analysis, which is lacking from many other approaches, which tend to focus exclusively on either the quantitative MCDA type approaches or softer qualitative problem structuring methods.

4.6 Summary and research gaps

An overview of approaches to decision problems and decision analysis was initially discussed from a pragmatic realist perspective and decision problems in environmental contexts were generalised to involve problem formulation and the evaluation of options. This section of the literature review was broadly split into problem formulation, and evaluation of options.

The need for stakeholder engagement in sustainability and value related matters was a strong theme emerging through the literature in Sections 2.2.2 and 2.3.1. Therefore, stakeholder engagement techniques were considered in the design and construction context with respect to the type of engagement required in order to make more sustainable decisions. This looked at the state of the art in stakeholder theory, which outlined that whilst much progress has been made over recent years, much territory remains unchartered. This included the question, *"what does value mean to a group of stakeholders?"* This research will utilise techniques in a workshop environment to consider what stakeholders define as sustainability and also consider what they value through the process. Additionally, whilst many authors stated that stakeholder engagement was an important aspect in relation to sustainability, there were very few examples of how this should be done. Many papers reference high level approaches for engaging stakeholders i.e. workshops. However, workshop techniques were generally not very well discussed. Therefore, this is one area on which this research will build.

Problem structuring methods (PSMs) were reviewed as approaches to structure complex issues, rather than solving well defined problems. This considers a range of techniques and their associated tools, and reviews these with the intention that they can be used as inspiration for structuring what sustainability means in the project context. The intention being to utilise what emerges from these sessions to help structure decision objectives. Then more quantitative approaches of assessing performance of options and informing the selection of roof options can be made.

Problem structuring methods are aimed at better defining and structuring the problem situation. They combine elements of operational research with the direct engagement of stakeholders and draw on local knowledge of the problem context. Most PSMs have been used on large scale infrastructure, or natural resource management issues, of great scale, impacting large regions or in the organisational setting. Application in the context of smaller construction projects has been limited. Additionally, none of the PSMs reviewed were considered suitable for application in their own right with respect to roof selection, as it was considered that engaging stakeholders with respect to choosing a roof system may seem a little abstract. Therefore, it was considered more appropriate to engage them at a project scale, looking at defining what should be considered from a sustainability and value perspective.

Techniques applied to inform decision making in construction contexts have typically ignored stakeholder views and applied MCDA techniques to optimise the performance of options based on objectives decided by a central decision maker or defined from the literature. Additionally, MCDA techniques have typically been used at a large scale. Whilst MCDA techniques have been used in roof selection, as discussed in Section 3.7 it is argued that in the case of Grant (2007) where there was no engagement from stakeholders in the development of the objectives, her objectives were largely considered irrelevant to particular projects when reviewed with stakeholders. Additionally, with respect to McCourt (2007), who used value focused thinking to structure the means objectives for roofs, did so via interviews and thus did not engage a broader set of stakeholders in the values definition process. This work seeks to build upon this work by developing techniques to engage a broader group of stakeholders to consider what represents sustainability, and also encourage them to bring a more diverse range of local knowledge into the process, as well as address other limitations in their approaches.

Pragmatic realist approaches, combining softer approaches to engage stakeholders in the problem situation and setting of objectives and following this with harder MCDA decision analysis techniques have been applied in other contexts. However, this is very much an emerging field and where this has been done it has mostly been at a much greater scale than selecting systems on building projects. For example, considering regions with respect to watershed management and also forestry and typically over a long time period. However, these have mostly been used outside the context of this research at a broader scale. This research is looking to develop a pragmatic realist approach aimed at informing decisions with respect to the design of buildings and in particular the selection of a building sub-system such as a sustainable roof.

Value focused thinking was identified as an approach to bring together the values of stakeholders and the quantitative analysis of multi-criteria decision analysis techniques. Additionally in the value focused thinking methodology, Keeney advocates considering both strategic objectives for the decision context and fundamental objectives as a way of achieving strategic objectives. With respect to roof selection, it is considered that the roof selection should align with the strategic (project) objectives. Value focused thinking was identified as a structured approach to combine stakeholder values with the scientific performance information of different roof system options.

The literature review found examples of the use of stakeholder participation techniques, included in PSMs to structure decisions. Whilst PSM techniques have been used in other fields, they have not been explored in depth in informing decisions on building projects. The lack of use of stakeholder participation techniques from other disciplines in the building industry is therefore identified as a research gap.

The second research gap identified through this review of the literature, includes a movement towards mixing methods, from stakeholder participation techniques, to harder quantitative techniques such as MCDA. This author refers to these as pragmatic realist approaches to sustainability that mix methods according to the purpose of the work. Such a combination of qualitative participatory techniques and quantitative techniques such as MCDA have not been broadly applied in the context of this research. Therefore, the lack of application of pragmatic realist approaches to sustainability in the building industry is something that this author wishes to address.

4.7 Conclusion

This section has considered approaches to decision problems and decision support from other disciplines and considered a range of techniques from other disciplines that are typically not used in the construction industry. This includes a range of problem structuring methods and techniques to the evaluation of options. It has also considered the recent call for a use of a combination of approaches in mixed methods to addressing problems. These take a pragmatic, realist stance, which is typically not utilised in the construction industry. These appear to have merit in other fields and therefore the following research gaps have been identified.

- The lack of use of stakeholder participation techniques from other disciplines
- The lack of application of pragmatic realist approaches to sustainability in the building industry

These research gaps are used to inform the development of the research questions and associated research objectives as detailed in Section 5.2.

5 Research approach and strategy

5.1 Introduction

This section develops the research questions and associated research approach and strategy based on the research gaps identified in the literature review. It also considers the philosophical position of the research, the research approaches used, the broad research strategies, time horizons and summarises the data collection methods. Whilst more detail is included in the individual parts of the thesis regarding the specific data collection methods, this section intends to give a high level overview of the approaches used. This section uses the research process ‘onion’ as defined by Saunders et al. (2003) as its structure (Figure 5—1).

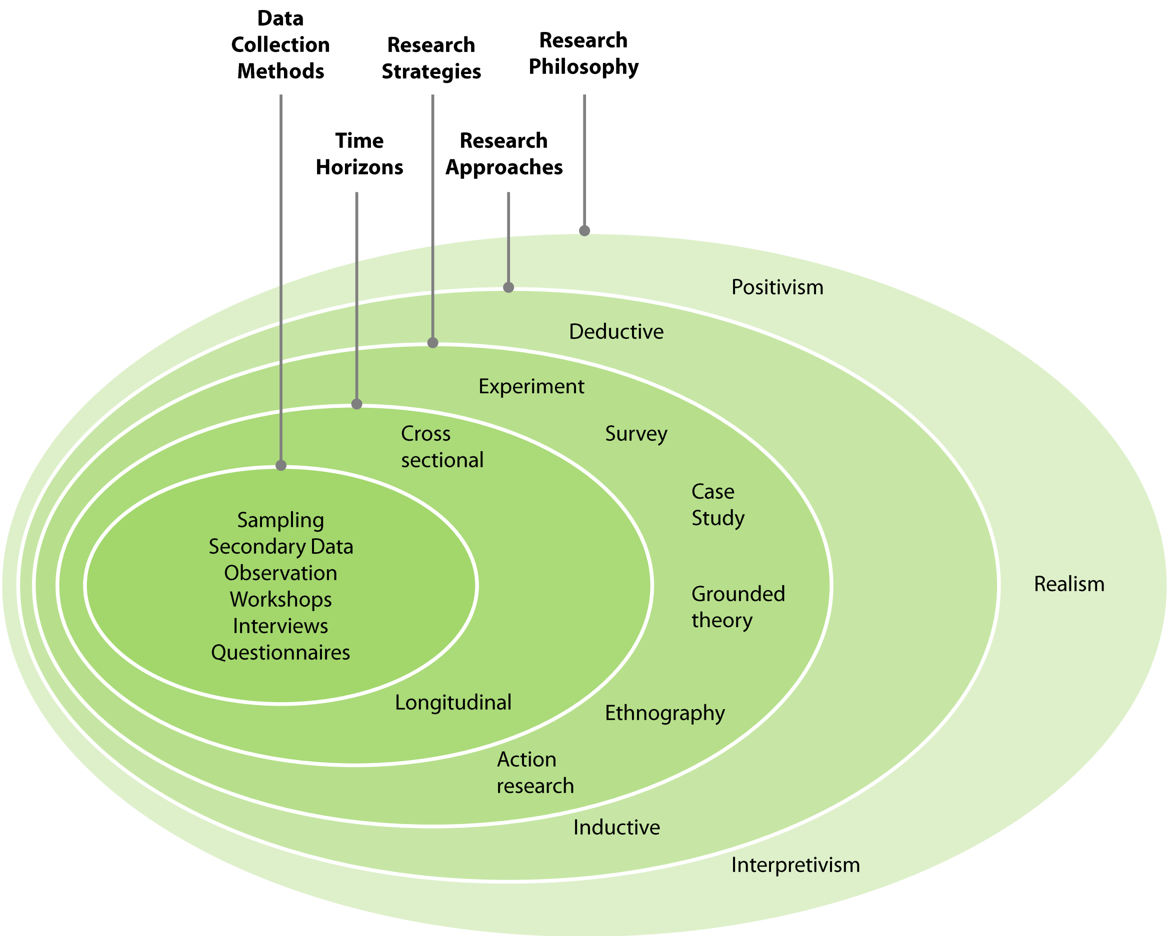


Figure 5—1 The research process ‘onion’ after Saunders et al. (2003)

5.2 Research aims, questions and objectives

Emerging from the literature review were key areas of further work as summarised by the research gaps below. These have helped define the research questions and associated objectives for this thesis.

Research Gaps Emerging from Literature Review – Sustainability for Building Projects:

- **Lack of stakeholder driven approaches to defining sustainability to consider the project context in the building industry:** From the building environments literature, the focus on assessment systems has traditionally being around developing centralised systems with set criteria that are then generalised across all projects they are applied to. They have little ability to reflect local project circumstances, or in fact align with the specific aims of the project. Therefore, there has been a call by several authors for the development and use of more participatory and context based approaches to informing sustainability through the building design process (see Section 2.3.1).
- **The insufficient exploration of methods for integrating environmental, social and economic value:** There was a developing need to provide techniques that integrated environmental, social and economic value and go beyond the environmental focus of environmental assessment methods. This also includes the need to consider sustainability and value together, as discussed in Section 2.3.2.
- **The need for approaches that address the challenges of the design process:** Numerous challenges of the design process were identified in Section 2.3.3, which included the need to consider how assessment can be used to better inform design decisions in the early project stages, as it is recognised that assessment typically happens retrospectively in the later stages of design. This requires information at the project stages when it is generally most limited.

Research gaps emerging from the *'literature review – sustainable roof selection'*:

- **The limitations of current decision support methods for roofs:** Current decision support tools for roofs have their limitations, as they are typically developed for a specific context. In the case of Nelms (2007), Grant (2007) and McCourt (2007) these were all developed in and for the North American context and paid limited attention to engagement with stakeholders, or how to acquire appropriate roof performance data early in the design process. There are also opportunities to improve consideration of risk, and how roof performance criteria relate to wider project criteria. These areas are discussed in Section 3.7 and 3.8.
- **The lack of a structured approach to acquiring roof performance information to reflect the project's context:** Whilst there is much performance information on roofs amongst the literature, there is need for a structured way to acquiring roof performance of various systems that is relevant to a particular context. One of the challenges of the design process is that options and designs often have to be developed and selected within a short timeframe. How to support this decision process is a research question that is actually posed by Grant (2007), in her doctorate thesis, as an area of further work. Additionally, in her work, interviewees when asked about her framework, did not look highly on certain aspects of the way things had been quantified, such as the use of the cool roof calculator as a measure of energy savings. They stated that a database of energy performance, especially one tailored to a small geographical area would be useful. Nelms (2007) also notes the potential benefits of order of magnitude estimation models that provide insight into performance. This is discussed in Section 3.7 and 3.8.

Research gaps emerging from the *'literature review – identifying decision support methods for complex contexts'*:

- **The lack of use of stakeholder participation techniques from other disciplines:** This part of the literature review considered techniques that had been designed to support parts of the decision making process in relation to complex problems, but which have not typically been applied in the context of the building design industry. It identified numerous approaches to the definition of decision making criteria and complex problems, and also approaches to the assessment of options. Approaches such as stakeholder participation techniques and problem structuring methods are considered useful from other disciplines.

- **The lack of pragmatic realist approaches to sustainability in the building industry:** Approaches in construction do not generally reflect the participatory nature of sustainability and the discourse that much of the broader sustainability literature generally advocates. More pragmatic realist approaches have been applied in other sectors, i.e. watershed management, forestry management, and conservation biology. Pragmatic realist approaches to sustainable decision making, mix methods depending on the purpose. There is a growing set of literature that mixes techniques such as PSMs and multi-criteria decision analysis. Value-focused thinking was also identified as an approach to bring softer techniques together with harder quantitative approaches. The research will take inspiration from these approaches in the development of an approach to sustainable roof selection in the building industry. The evidence of the development and application of pragmatic realist approaches in the construction industry on projects with clients is sparse. Therefore, testing the feasibility of their application to the construction industry is a current gap in the research.

Whilst other research gaps were identified through the literature review, such as an emerging body of literature concerned with building assessment methods not addressing sustainability from a scientific viewpoint such as that outlined by the natural step, these are not considered the main focus of this research. This is because the approaches developed are intended to be optional approaches and not to be enforced by regulations. Therefore, it is considered that the approaches will have to be seen to be offering improved choices with respect to project value. Whilst “strong” sustainability perspective places an emphasis on maintaining natural capital, which is non-substitutable, it is unlikely at the present time that clients and stakeholders will see the value in this, unless education is undertaken. This is important, but is considered beyond the realms of the research and the current mind-set of the industry. The research questions and associated objectives to address the above research gaps are detailed below.

The overarching research aim is, ***“to develop a pragmatic realist approach to decision making to inform sustainable roof selection in the context of building design.”***

To do this the following research questions have been defined:

1. Is it feasible to develop stakeholder participation techniques to engage project stakeholders in defining project sustainability and value themes on which to base design decisions that integrates:
    a. stakeholder values and preferences?
    b. environmental, social, and economic value?

c. stakeholder knowledge, rather than considering purely expert knowledge?

2. Is it feasible to develop an approach and decision support tool to inform roof selection that:
    a. allows the rapid definition and assessment of different roof systems?
    b. reflects the participatory nature of sustainability and allows for the consideration of stakeholder values?
    c. incorporates context specific locally-relevant information from research on roof performance?

The relationships between the gaps in the literature and the research questions are shown visually in Figure 5—2.

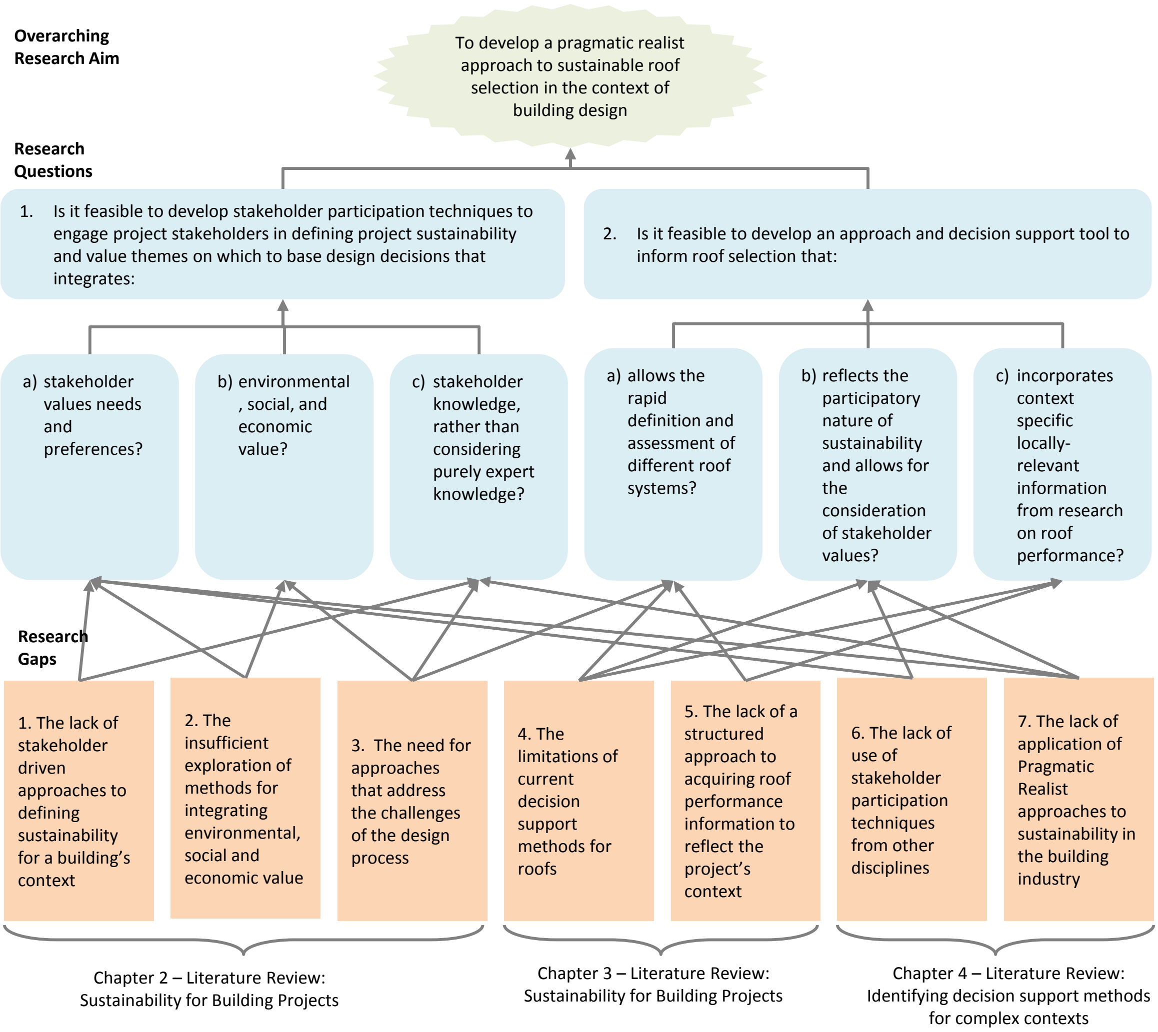


Figure 5—2 The development of research questions to address gaps in the literature

In order to answer these research questions a set of objectives has been developed which are shown in Figure 5—3.

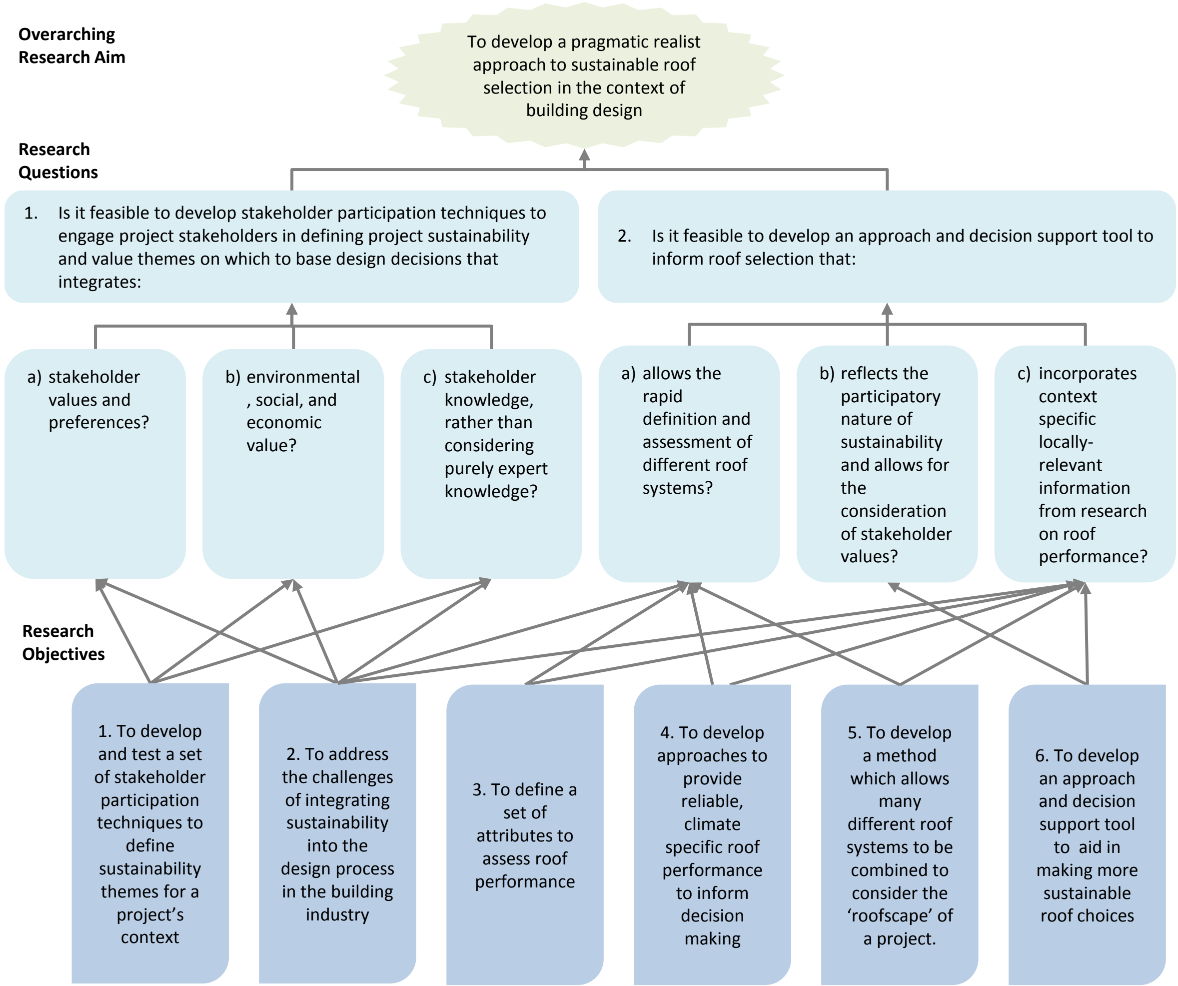


Figure 5—3 Research objectives to answer the research questions

It is considered that the research question 1 is addressed through Part 1 of this research, through the development of a set of engagement techniques to define sustainability and the testing of these in the project context. It is considered that the development and testing of these techniques in the industrial context, through action research with application on client facing projects, would ensure that they addressed the gaps in the literature with respect to the need for approaches that address the challenges of the design process. This would also provide the documentation of stakeholder driven approaches to defining sustainability for the building's context and consider the integration of environmental value with social and economic value, which were identified as two other gaps in the sustainability assessment literature in the building industry.

Question 2 is addressed through Part 2 of this thesis. This is done by meeting research objectives 3 – 6.

To address research question 2a, it was considered that a way of defining a set of attributes to assess roof performance was required, as well as approaches to defining reliable, climate specific roof performance information and a method to consider different roof systems to be combined on a “roofscape”. Question 2b is answered through the development of an approach and decision support tool, which incorporates approaches developed through Part 1 of the thesis to reflect the participatory nature of sustainability and considers how this relates to roof performance attributes. Question 2c combines elements of objectives 3 - 6 to consider context specific information into the approach and decision support tool.

5.3 Research philosophy

The research takes an overall pragmatic realist approach lying between the positivist stance of natural science and interpretivist stance, as shown in Figure 5—1. This has been heavily influenced by the literature review on different philosophies and approaches to sustainability and sustainable development, as well as the research being set in an industrial context. The philosophy is considered pragmatic, in that approaches are chosen to best answer the research questions and mixes methodologies appropriately.

Saunders et al. (2003) explain that realism shares some philosophical aspects with positivism, for example, related to the external, objective nature of some macro aspects of society. However, realism also considers that people are not objects to be studied in the style of natural science. In this way, realism, as applied to the study of human subjects, recognises the importance of understanding people’s socially constructed interpretations and meaning, or subjective reality, within the context of seeking to understand the broader social forces, structures or processes that influence (and perhaps constrain) the nature of people’s views and behaviours. The positivist, pragmatic realist and indicative normative approaches to sustainability are all discussed in Section 2.2.2. The philosophical stances and approaches used to attempt to define and deliver sustainability are much discussed in the literature and are important considerations for this research.

The research is conducted in a ‘real-world’ environment and it therefore has a real world emphasis, rather than a purely academic perspective. The difference between the two types of research are outlined by Robson (2002) and are shown in Table 5—1.

Table 5—1 Real world research emphasis vs. academic research emphasis after Robson (2002)

Real World Research Emphasis	Vs.	Academic Emphasis
Solving problems	*… rather than ….*	Just gaining knowledge
Predicting effects	*… rather than ….*	Finding causes
Looking for robust results and concern for actionable factors	*… rather than ….*	Statistical relationships between variables
Developing and testing services	*… rather than ….*	Developing and testing theories
Field	*… rather than ….*	Laboratory
Outside organisation (e.g. business)	*… rather than ….*	Research institution
Strict time and constraints	*… rather than ….*	R&D environment
Researchers with wide-ranging skills	*… rather than ….*	Highly specific skills
Multiple Method	*… rather than ….*	Single Method
Orientated to client	*… rather than ….*	Orientated to academic peers
Viewed as dubious by some academics	*… rather than ….*	High academic prestige

The overarching philosophy adopted for this research is to acknowledge rather than reduce the complexity of sustainability. Therefore, through this research the author hopes to embrace methods that go beyond those of normal assessment systems used in the industry and utilise approaches from other disciplines to achieve a stronger understanding and definition of the context. This research addresses issues to do with current methods of defining and measuring building performance with respect to sustainability, which are often based on context independent measurement systems that suffer from Macnamara's fallacy of (Handy, 1995):

- Measure only what can be easily measured;
- Value arbitrarily what cannot be measured easily (artificial and misleading);
- Presume if it can't be measured it is not important (blindness);
- Or if it can't be measured easily it doesn't exist! (suicide).

The methods applied align with the overall principles of those outlined in value focused thinking (Keeney 1992) and thus the approach is heavily influenced by this. However, the research presented in this thesis aims to expand upon this by utilising and testing techniques within this structure to facilitate groups of stakeholders to be able to communicate their values and be able to bring these together to define common sustainability and value decision objectives. It is concerned with informing more sustainable roof selection decisions with respect to the context of the project, and thus aims to combine technical performance data based on science and stakeholder values through multi-criteria decision analysis, as detailed in Figure 5—4.

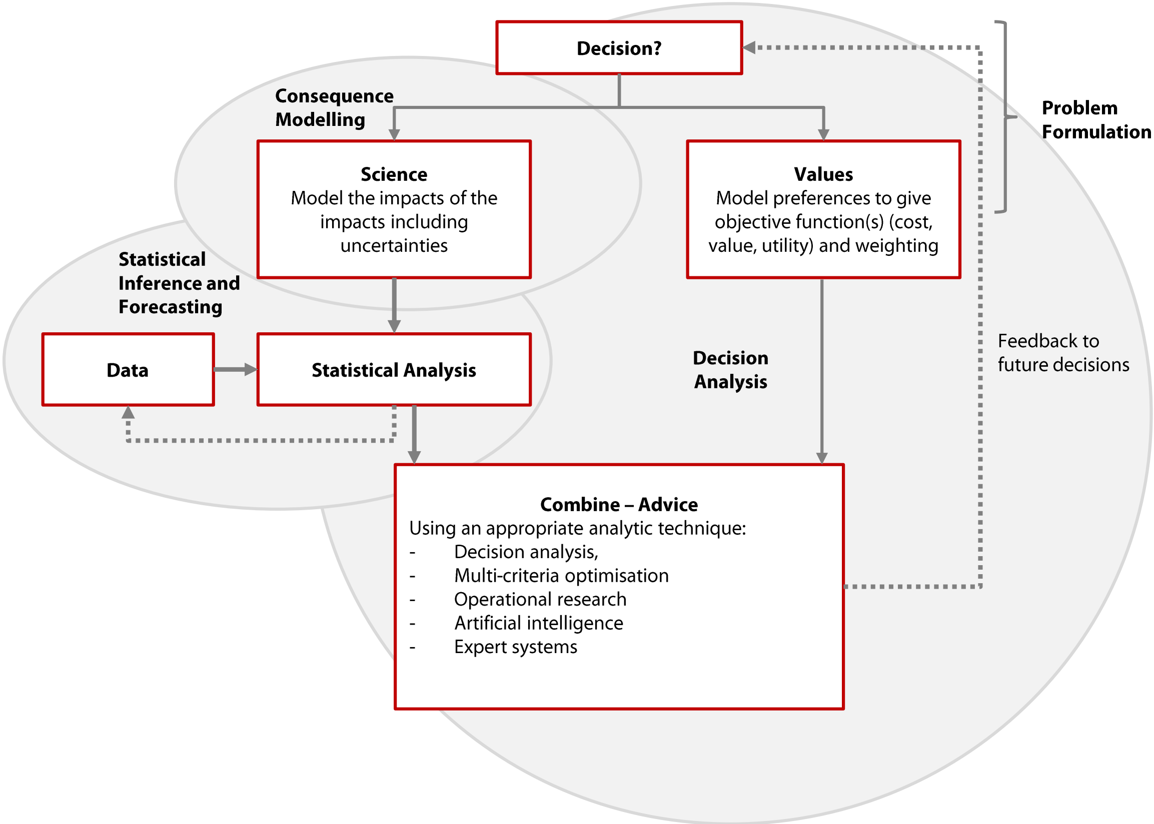


Figure 5—4 Analysis underpinning the stage "evaluate options" after French and Geldermann (2005)

The following sections discuss the ontological, epistemological and axiological assumptions of the research.

5.3.1 Ontology

Ontology is concerned with the nature of reality and what assumptions do we make about the way in which the world works. These can be broadly considered with respect to objectivism and subjectivism. The stance here of the pragmatist researcher depends on the research question. The researcher’s view of the nature of reality, changes to best enable answering the research question. For example the researcher, with respect to what the stakeholder considers sustainability to be, takes acknowledgement of subjectivity, but with respect to the performance of different roof systems, takes a more objective approach. However, with respect to how roofs perform with softer aspects of performance, such as aesthetics, a subjective view is considered appropriate.

5.3.2 Epistemology

Epistemology is concerned with what constitutes acceptable knowledge in a field of study. This is concerned with the positivist vs interpretivist elements of knowledge. The view of the pragmatist, with respect to this research, is that observable phenomena and subjective meanings can both provide acceptable knowledge dependent upon the research question. Again elements of the research are concerned with the performance of roof systems in different contexts, which require consideration from a positivist perspective. However, elements in relation to understanding what is important from a value and sustainability perspective are considered from an interpretivist perspective. This is combined through a mixture of methods into an approach to decision making. This reflects the critique of approaches to sustainability that lie at the extremes of positivistic sustainability and normative sustainability, as discussed in the literature review in Section 2.2.2.

5.3.3 Axiology

Axiology is concerned with the researcher’s view of the role of values in research. The pragmatic approach of the research acknowledges the role and importance of values in the research. The researcher whilst sympathising with the need to maintain natural capital, does not take a strong sustainability view. Instead, a weak sustainability view is taken, as described in Section 2.2.1. Weak sustainability is based on the assumption of neo-classical economics that man-made capital is a near perfect substitute for natural resources (Daly, 1990, Victor, 1991). This seeks to maximise economic, social and environmental value for a given decision based on the perspectives of the project stakeholders on what is considered important, but allows the substitutability of different forms of capital. This is reasoned in much more depth in Section 2.2.1 and summarised in Section 2.4.

5.4 Research approaches

The situations in which sustainability consultants and engineers have to make decisions with respect to value and sustainability exhibit the characteristics of messy and unstructured problems, which are characterised by the existence of the following (Mingers and Rosenhead, 2004). Note that the accompanying text in italics gives an example of each within the context of roof design and selection.

- Multiple actors: *engineers, architects, clients, project managers, wider project stakeholders etc.*
- Multiple perspectives: *different value sets, some keen on sustainability, others wanting quickest payback at the expense of everything else.*
- Incommensurable and/or conflicting interests: *for example developers may have no strong drivers to develop sustainable buildings, as they will not necessarily be paying utility bills, and repairing poor design through the life cycle of a building.*
- Important intangibles: *Many of the most important aspects of sustainability are difficult to measure. For example social aspects are difficult to quantify and often there is little data for many aspects, such as the life cycle impacts of materials*.
- Key uncertainties: *The design and use of buildings is inherently uncertain. This is due to the relatively long term life cycle of buildings and numerous refurbishments and use patterns typically occurring through the life cycle.*

Such problems can rarely be addressed from just one type of research method. Therefore, the research has used a multi-method approach, utilising a plurality of methods, both qualitative and quantitative, within real-world interventions (Mingers and Brocklesby, 1997).

The research approach has been conducted using mostly inductive approaches. For example, in developing approaches to understanding sustainability and value in Part 1 of the research, the techniques used are not based on testing a hypothesis (as would have been the case in a purely deductive research); instead, approaches have been developed through considering theory from the literature and developed, tested and refined through action research. It was considered that the complexity of the problem situation makes isolating variables and testing specific relationships extremely challenging. Additionally, the deductive approaches tend to adopt a rigid methodology that does not permit alternative explanations of what is going on. Therefore, an inductive approach allows theories and methods to be defined from the data rather than vice versa. The action research was therefore adopted as a way to develop and test techniques, with the intention of better understanding the needs and sustainability perspectives of the stakeholders within an industrial time frame. Iterative learning loops, including reflection on the processes, being used to build a more robust, reliable and valid set of processes for use within the project contexts in the building industry. The purpose of developing approaches to better understanding sustainability within the project context, being that once a set of objectives emerges, a framework for quantitative decision making can then emerge.

The approach also utilises inductive approaches to inform the requirements for the approach to decision support through an action research based case study with the purpose of understanding the challenges of roof selection on a real world project. Through trying to apply techniques in practice and inductively capturing the difficulties of doing this in the project environment, it was intended that the challenges with respect to roof selection would emerge and provide a set sub objectives on which the development of an approach to sustainable roof selection could begin to address.

Part 2 of the thesis has utilised leading building environmental modelling techniques, which have been built based on physical principles tested using deductive positivistic approaches, often through experiments. Whilst, these techniques were not defined by this researcher, it is important to acknowledge the research approaches that such techniques were developed from. This research develops a way of bring the results of the use of such techniques and the most appropriate modelling procedures together based on parameters defined as important in the literature.

Roof performance attributes are identified from the literature and the approach utilises techniques such as a multi-criteria analysis based on the SMART, with the value-focused thinking framework being used to consider the alignment of roof performance attributes with the overall objectives of the project. These are integrated into an approach to inform sustainable roof selection.

5.5 Research strategies

A number of research strategies were reviewed, which included experiments, surveys, case studies, action research, grounded theory, and ethnography.

The overall research strategy chosen for Part 1 of the research was that of action research. Action Research (AR) is an approach initially developed by Kurt Lewin who articulated AR to be, *“a way of generating knowledge about a social system, whilst at the same time trying to change it”* (Lewin, 1946).

AR aims at building and/or testing theory within the context of solving an immediate practical problem in a real setting. It combines theory and practice, researchers and practitioners, and intervention and reflection. It is particularly suited to the needs of this research and also the context of the researcher who was integrated within a project team in the sponsoring organisation.

Hult and Lennung (1980) state the following three characteristics with respect to how AR is different from other research approaches:

- It aims at an increased understanding of an immediate problem situation, with emphasis on the complex and multifaceted nature of organisations.
- It simultaneously assists in practical problem solving and expands scientific knowledge. This goal extends into two important process characteristics
    - Highly interpretive assumptions are made about the observations.
    - The research intervenes in the problem setting.
- It is performed collaboratively and enhances the competencies of both research and practitioners. It links theory and practice to generate a solution.

It is described as a research approach/strategy rather than a research method. Additionally, it differs from such typical methods used in construction and engineering management, such as surveys and case studies, as such methods typically assume that the research does not affect or interface with the situation which is being studied (Naoum, 2001).

Saunders et al. (2003) detail that there are 4 common themes within the action research literature.

- **Clear purpose to research:** The purpose of the research was clear as to find better ways of understanding what sustainability and value meant in the project context, so that decisions with respect to building systems (in this case roofs) can be based on these objectives.
- **Involvement of practitioners in the research:** Practitioners from the sponsoring organisation, as well as external stakeholders and clients to projects, were involved throughout the research, which was undertaken in an industrial setting. Therefore, the researcher was part of the organisation within which the research and change process are taking place.
- **Emphasis on iterative nature of research:** The research was iterative in nature, and involved the process of diagnosing, planning, taking action and evaluating. The diagnosing was initially undertaken by a review to understand the problem situation and then explored this through workshops inside the sponsoring organisation. Planning again involved identifying, from the literature, potentially suitable techniques for applying and also refining these techniques with experienced professionals in the sponsoring organisation. This process itself was one of diagnosing, planning, taking action and evaluating on a smaller scale in order to define an approach, which was suitable for application with clients. Different approaches to defining sustainability were then tested on three case study projects, and a variety of formal and informal feedback was received and formed part of the evaluation and learning cycle.
- **Has implications beyond the immediate project:** The overall goal of this research was around better definition of sustainability and value for a project. The action research considers projects individually, but as the research was conducted first within the sponsoring organisation, then applied on a longitudinal set of projects, learning from one project was incorporated into the approach for the next project, with changes and refinements made based on the learning from previous projects. Therefore, whilst only a small sample size, the action based research has implications beyond the immediate project that it was tested on.

An action based research, fits within the pragmatic realist approach that has been undertaken and also allowed techniques and methods identified in the literature to be tested in the project arena, which was important due to the industrial setting of this research. Although an action research approach is seldom taken in construction engineering and management, it has a number of advantages within the context of this research. Azhar et al. (2010) concluded that it is a reliable, structured and rigorous research approach for conducting applied research in construction and enabling academia to influence and improve construction industry practices. However, Azhar et al. (2010) state that the Action Research Methodology is not typically used in the construction industry, with only a few examples identified and those had little elaboration on their approach.

For each element of the action research, data was collected utilising a variety of methods, which are detailed in Section 5.7. These included surveys and workshops. The specific survey and workshop techniques applied were derived from, or inspired by, those identified in the literature review and tested internally through surveys and workshops, before being applied in the context of case study projects.

With respect to Part 2 of the research, an action research case study was undertaken where the researcher was based in the sponsoring organisation and looked at the challenges and difficulties of informing sustainable roof selection on a real building design project. The purpose of this work was to identify some of the challenges of trying to inform roof selection on a project, in order to be able to use these to add to the literature and also help set the objectives of the decision making approach.

The final part of the research involved developing the approach to sustainable roof selection based on learning from the literature, challenges identified from the case study research and incorporating engagement techniques, which were explored in Part 1 of the research. This considered the output of the action research approaches, utilising techniques in the case studies 1A, B and C and then considered how quantitative MCDA techniques could be integrated within an overall approach to sustainable roof selection to make a more sustainable choice. This involved categorising and analysing existing research and secondary data sources in order to meet some of the challenges of requiring information quickly at the early design stages of the project, to be able to have informed data on the performance of different aspects.

This is then presented as an approach to pragmatic realist sustainable roof selection. The limitations of the approaches used and areas of further work are then identified.

5.6 Time horizons

Figure 5—5 shows the timeline for main aspects of this research. With respect to Part 1 of the thesis, the approaches used for defining sustainability and value in the project context, were developed and refined based on the learning from earlier case studies as part of the action research approach and thus should be considered a longitudinal approach. With respect to Part 2 of the research, Case Study 2A employed an action research case study in an industrial context. Whilst this overlapped with the action research strands in Part 1 of the research the collective learning from both parts of the research were used to inform the overall approach in the development of sustainable roof selection.

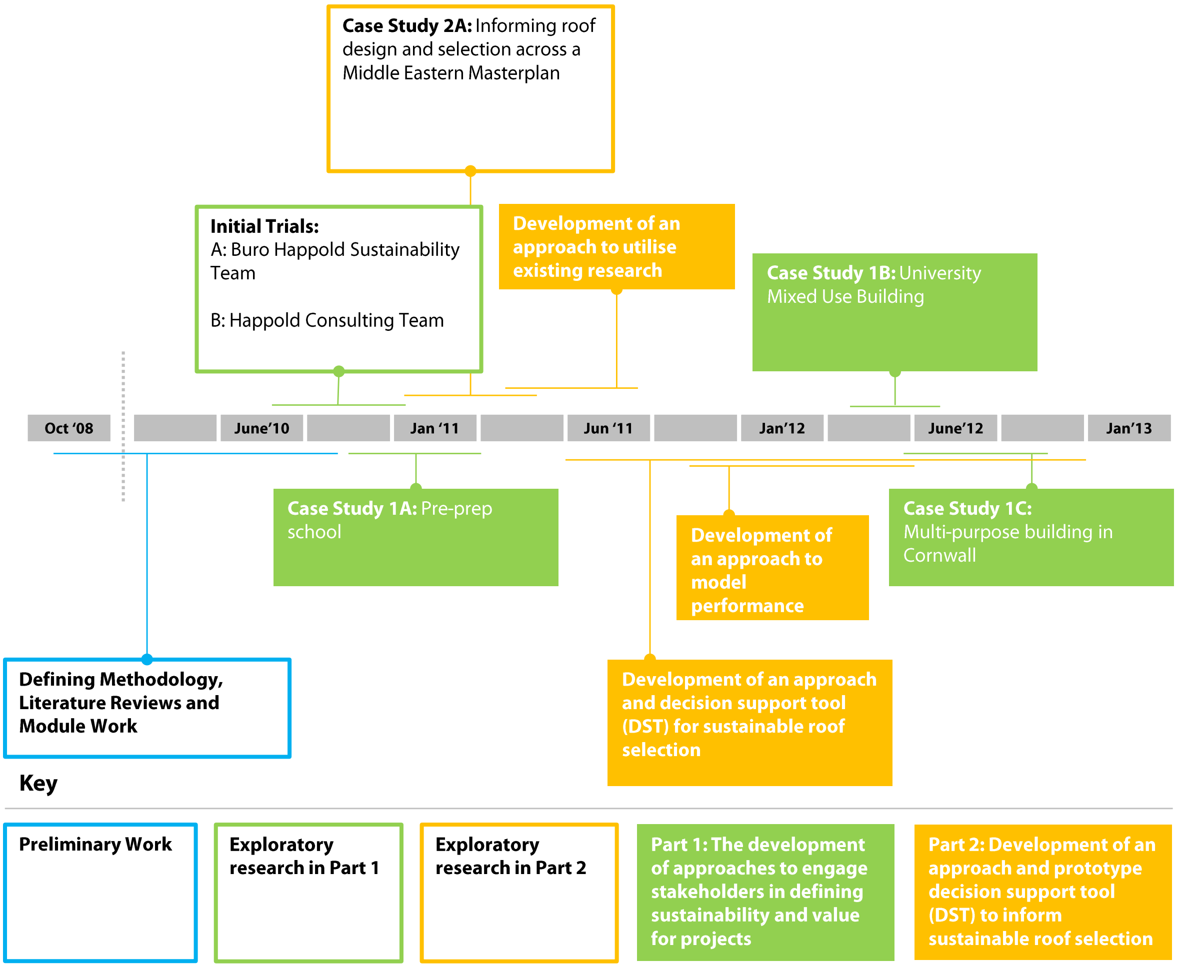


Figure 5—5 Timeline of work

For example prior to the three case studies undertaken for Part 1 of the research, the concept of value and eliciting value through a combination of questionnaires and workshops was discussed and the methods tested in workshops inside the sponsoring organisation. This included a workshop with the Buro Happold Sustainability Team in August 2010 and a workshop with the sister company, Happold Consulting International, in January 2011 (results from the trial questionnaire are included in Appendix E). This tested part of the questionnaire that was used in Case Study 1A, but also based on suggestions from the workshops; additional context specific questions were developed for Case Study 1A. Thus, learning from trials and early case studies fed into the development of approaches and material used in later workshops.

Additionally, as the action research case studies were conducted on real life projects, certain omissions had to be made due to time and resourcing issues. However, the research is therefore considered to reflect the time pressured nature of industry. Therefore, the multi-method approach has been undertaken in a series of real world interventions.

Where feedback has been acquired it is discussed and the approaches are rationalised where they have been further developed from academic literature. Additionally, the success of the approaches is not statistically determined, but is discussed in relation to the academic literature and how it addresses gaps in the literature. The next section discusses the data collection methods that were used for the various elements of the research..

5.7 Data collection methods

The data collection methods have also followed a multi-method approach. However, the methods were always selected based on the purpose of the work. The case studies presented in Part 1, therefore, utilises a series of questionnaires, structured and facilitated workshops and applying novel engagement techniques to elicit what represents sustainability on real world projects. The methods have been heavily influenced by stakeholder engagement, facilitation techniques, and problem structuring methods, as detailed in the literature review. All work has been conducted on real life projects in the context of a sustainability consultant working in the company's sustainability team. These have been applied in contexts outside of their typical use, often being modified to reflect the challenges of the design process, as outlined in the literature review and further explored in Case Study 2A, looking at influencing roof selection on a real project. The researcher is therefore fully involved and not external to the approach and results, which is typical of a pragmatic realist approach. However, it should be noted that there are limitations to this approach, as there are to any approach and these are further discussed in the "Reflections on research" in Section 16.

The methods used in Part 2, initially involve a literature review to identify the key challenges and areas requiring further work. The original work conducted then includes a descriptive action research case study of the problem situation, in which the researcher working on a real world project tried to inform the decision making with respect to sustainable roof selection, utilising the techniques that were available at the time, with the intention of understanding the challenges of informing sustainable roof selection in the context of the project. This action research case study, in combination with the literature review, provides the basis for the development of an approach and prototype roof decision support tool to inform sustainable roof selection.

The roof decision support approach was then developed, based on leading techniques identified in the literature, whilst also considering the project constraints. This involved a comprehensive literature review looking at the performance of different roof options and also the ability of a roof to influence many areas traditionally related to sustainability. The approaches aim to gain secondary data from the literature for use in decision making. Other data methods involve utilising the latest modelling techniques to provide data for the prototype decision support tool. These techniques have typically been validated by other researchers utilising a positivistic research philosophy and data collected through experiments. Additionally, with respect to techniques used in providing the data required for the prototype decision support tool, only widely accepted techniques and secondary data published in journal papers has been used.

Table 5—2 outlines the various data sources drawn upon through the research. It considers:

- **Research aspect:** the particular part of the work (i.e. the case study that is being referred to).
- **Duration and period:** When the data was collected and for how long.
- **Data source:** a description of the broad technique used to collect the data, for example workshops, questionnaires, presentations with opportunities for feedback.
- **Role of the researcher:** The researcher's involvement in the collection of data.
- **Purpose:** The reason for collecting the data.
- **Data Type:** A description of the data output and type. In Table 5—2 this describes whether the data collection method is quantitative or qualitative. As quantitative and qualitative can be easily misinterpreted, this research utilises the Saunders et al. (2003) description. One way of distinguishing between the two is the focus on numeric (numbers) or non-numeric (words) data. Quantitative is used as a synonym for any data collection technique (such as a questionnaire or experiments) or data analysis procedure (such as graphs or statistics) that generates or uses numerical data. In contrast, qualitative is used predominantly as a synonym for any data collection technique (such as a workshop) or data analysis procedure that generates or uses non-numerical data. However, qualitative data (i.e. a set of post-it notes), collected through a workshop, could be analysed in quantitative means through, for example, categorising post-it notes of a workshop and counting the number of times a particular category emerges.
- **People involved:** The number of people involved and their backgrounds.

Table 5—2 Data sources through the research

Research aspect	Period	Data Source	Role of Researcher	Purpose	Data Type	People Involved
Part 1 Exploratory Research- Case Study 1A	24/08/10	Exploratory Workshop	Structured, Facilitated and Captured Output from Workshop	An initial exploratory workshop was held with the Sustainability Team to understand their perspectives on value..	Qualitative Data comprising of notes capturing a definition of what represented value to each of the workshop attendees.	8 people involved ranging in experience from graduate to director (partner)
Part 1 Exploratory Research - Case Study	Nov 2010 (Sust-ainbilit-	2 Trial Surveys utilising the Schwartz Values Survey	Circulated SVS questionnaire and undertook analysis of	The first trial questionnaire was circulated to the members of the	Individual and group results summarised to the group in a	9 responses from Sustainability – sample size 11

Research aspect	Period	Data Source	Role of Researcher	Purpose	Data Type	People Involved
1A	ity) Dec 2010 (HCI)		results.	sustainability team A second trial questionnaire was then circulated to the members of Happold Consulting International (HCI). The results were then presented in a Workshop	follow up workshop and also a short concise document. This was followed	(representing a response rate of 82%). 24 Responses from HCI - sample size 42 (representing a response rate of 56%).
Part 1 Exploratory Research - Case Study 1A	Nov 2010 to Jan 2011	Trial Workshops	Facilitated 2 No. Follow up workshops with Sustainability Team and Happold Consulting International	The results of both trial questionnaires were presented in workshops with the Buro Happold Bath Sustainability Team and HCI team and discussed. Feedback was obtained from each. A report was written up and circulated to respondees of the questionnaire and attendees at the workshop	Participant observation of discussion and feedback forms from the workshops.	7 People from the Sustainability Team attended the workshop. 29 people from the HCI attended the workshop.
Case study 1A	Nov 2010	Input from Project Manager	Dialogue with Project Manager	The modification of the Schwartz Values Survey (SVS) was done in collaboration with the Project Manager for the Project.	Used Feedback to modify the Schwartz Values Survey Questionnaire and add additional survey questions.	Researcher with Project Manager.
Case study 1A	Nov 2010	Values questionnaire circulated to pre-prep school	Structured Engagement Process, Analysed project brief and developed survey. Analysed Survey Results	The questionnaire was circulated in manual form and on survey monkey and was based on the SVS modified to include questions from	Quantitative Data Plots of individual and group values sorted by school role (i.e. management, teachers.	31 responses from a selection of teaching staff, management staff, the design team and governors. 26 were considered

Research aspect	Period	Data Source	Role of Researcher	Purpose	Data Type	People Involved
				their brief as well.	Qualitative Comments.	to be completed as described by the instructions..
Case Study 1A	Feb '11	Workshop and Participant observation	Structured Workshop, Presented Results and Facilitated Sessions	Follow up workshop to present results and discuss their feedback.	Qualitative data output. Workshop summarised and follow up discussions with Client. Article produced for internal magazine on the approach, results and client feedback.	8 stakeholders for the project, including management team, teachers, design team.
Case Study 1A	Jan '12	Feedback from Presentation to sponsoring organisation Global Executive	Wrote feedback on the process	Presentation to the company global executive, that is made up of the businesses most senior people (each regions Managing Director) on approach and follow up discussion and feedback	Discussion after the presentation. Follow up email sent to the attendees at the global executive	19 people including the senior partners, Managing Directors of the sponsoring organisation, including CEO.
Case Study 1A	Jan '12 to Jan '13	Numerous presentations and follow up discussion sessions as part of an Action Research approach.	Presentation of approach to numerous internal groups in Buro Happold and opportunity for discussion after the presentation	To present and discuss the approaches and hear feedback from a range of professionals	Qualitative	>50 people inside the sponsoring organisation
Case Study 1B	May '12	Dialogue with project team when developing approaches	Developed and refined techniques based on dialogue	To develop a set of workshop sessions to explore sustainability with stakeholders	Qualitative Data comprising of dialogue with practitioners	4 practitioners and researcher
Case Study 1B	May '12	Workshop with follow up report	Structured workshop in collaboration with	Structured and Facilitated a day long workshop	Summary of workshop output at the	24 attendees from 15 organisations /

Research aspect	Period	Data Source	Role of Researcher	Purpose	Data Type	People Involved
			Project Team and Project Leader, Developed Attendees Information Packs, Lead facilitator at the workshop, Analysed output content of workshop and wrote report for circulation to stakeholders.	(11:00-16:00). For agenda see Appendix G. Action research case study based research through workshop with 29 stakeholders	end of the workshop. Output report circulated to all workshop attendees.	university departments. 5 Facilitators of which the researcher was one.
Case Study 1B	May '12	Feedback Forms	Developed Feedback form, collected and analysed results.	Circulated at the end of the workshop. See Appendix H for example.	Quantitative and Qualitative Output.	12 Responses from 24 attendees (50% response rate)
Case Study 1C	May '12	Input from Project Partner	Personal dialogue with project partner.	Dialogue with Project Partner regarding the approach taken in Case Study 1B and how the approach could be applied in the context of Case Study 1C.	Feedback was given around how it was consider the approach would benefit from being spread over several sessions.	1 to 1 dialogue with project partner
Case Study 1C	May '12	Workshop 1 Notes from Workshop	Structured Workshop Sessions, prepared workshop material, lead facilitator at the workshop.	2 hour workshop	Participant observation Notes from workshop summarised into a short report summarising the key themes that emerged.	26 Attendees representing the major stakeholder groups of the project.
Case Study 1C	Dec '12	Workshop 2	Structured Workshop Sessions, prepared workshop material and analysed the output of the	2 hour workshop	Output from workshop and Feedback forms	17 attendees (3 of which were facilitators). This represented input from different stakeholders within the main

Research aspect	**Period**	**Data Source**	**Role of Researcher**	**Purpose**	**Data Type**	**People Involved**
			workshops.			organisations related to the project.
Case Study 1C	Jun '12	Feedback Form	Structure and Analysed feedback.	Circulated at the end of the workshop. See Appendix H for example.	Quantitative and Qualitative Data	5 feedback forms were received from 13 individuals
Case Study 1C	Aug '12	Workshop 3	Structured and Facilitated Workshop, Analysed output content.	1 hour workshop to present back results and incorporate feedback.	Notes captured and summarised in a table in relation to themes defined from workshop.	
Case Study 1C	Jul '12	Feedback Emails and Personal Correspondence	Collected Feedback.	Feedback from Project Manager and also others in the project team.	Qualitative Data	Project Manager Project Team Member
Case Study 2A	Dec '10 to Mar '11	Action Research Case Study	Emerged in project team, influencing and documenting the process	Defined, applied and reflected on approach on a case study project	Qualitative	Design team
Development of an approach to utilise existing research	Apr - Jun '11	Utilised secondary data from referenced journal papers	Systematically reviewed various forms of roof performance data from the literature and categorised this to consider applicability in other contexts.	To provide a structured and referenced dataset of roof performance data that can be used in the approach to sustainable roof selection	Quantitative data or performance formulae that can be used to assess performance in various variables (see review in Appendices O to S	Researcher only
Development of an approach to model performance	Oct '11 to Jun '12.	Utilised Energy Plus modelling package to generate data and the approach of Sailor (2008)	Developed an approach for running modelling on numerous roof options across numerous climates to generate climate specific roof performance data for roofs	To provide a structured and referenced roof performance data for use in the approach and decision support tool for sustainable roof selection	Quantitative data	Researcher only

Research aspect	Period	Data Source	Role of Researcher	Purpose	Data Type	People Involved
Developing the approach and accompanying DST to sustainable roof selection	Jan '11 to Dec '12	Example case study	Structured based on Value-focused thinking approach, considering	To bring together information with respect to the performance of roof systems, stakeholder values, in a way that ranks options and allows users to assess uncertainty and risk	Combination of qualitative and quantitative data.	Researcher only

The individual methods along with the results and analysis of their use are further detailed in the respective sections. These also include a critical reflection on the approaches used.

5.8 Boundaries of the research

Boundaries have been set in order that the research has focus and does not become too unwieldy. Each boundary is explained below:

- **Scale:** The scale chosen for the use of the decision support tool is global. Whilst this brings about significant challenges, regional examples have already been undertaken by various authors. Additionally, the generalisability of their approaches has been questioned by this author. In the context of the international consultancy, design consultants can be working on projects located anywhere in the world and therefore to be fit for purpose, a tool that is flexible for use in the global environment is considered necessary. Therefore, the tool should be suitable for application in this context. However, there is more information for some regions. Where the information used is not context specific this is highlighted as a risk to the user of the decision tool and the user always has the ability to over-ride any information from the datasets collected to be used in the decision support tool. References are given to all research and data used in the decision support tool. One of the contributions is to bring the vast and unorganised roof research together (with a particular emphasis on green roofs) and classify the work according to region and climate type. This has also been mapped geospatially using a variety of tools to inform the decision maker and ensure that they can reference the most appropriate information to inform the decision. Whilst the intended scale of use is global, it is accepted that the generalisability of the tool for use in the global context is not tested in this research.
- **Time frame:** The decision support tool seeks to consider issues through the life cycle of the roof. This is identified as an important consideration with respect to sustainability in the literature reviewed in Section 2.2.1. This considers the impacts of the materials used in the construction of the roof, the implications of the roof choice on the in-use performance of buildings from an energy, water, amenity space, provision for biodiversity etc. Consideration is also given to the durability, design life and maintenance requirements relating to the end of life considerations. Also with respect to the time frame of the project life cycle, the development of the tool is intended to be used at the start of the design process, when the ability to influence sustainability is high, and the cost of making changes is low (see Section 2.3.3).

- **Dimensions of Sustainability:** Consideration is given to aspects which could be categorised in the three broad areas of environmental, social and economic sustainability. This expands on traditional building rating systems which are typically focused on the environmental aspects of building performance. The value of the roof option is considered the trade-off between environmental and social value and economic costs. Additionally, it is considered pragmatic realist in its approach as it aims to bridge stakeholder values with hard performance data. However, the research does not take a strong sustainability stance, i.e. in assessing roof options it accepts the substitutability of different forms of capital (i.e. natural, financial, environmental).
- **Roof types:** The research considers only flat roof systems with a pitch of less than 10°. However, pitched elements such as solar panels can still be considered. This decision was made to eliminate many of the tiled or slate roof systems, which typically differ in characteristic significantly from flat roof systems. The list of roof types explicitly considered is included in Section 14.2.3.
- **Level of abstraction:** The research considers the roof as a whole system and assesses options accordingly. The research is less concerned with how specific products perform individually but rather the performance of the roof as a whole. It highlights different research that has considered the performance of green roofs, high albedo or cool roofs, solar photovoltaic and solar thermal roof systems. For each roof system, several options are provided, allowing the user of the tool some choice over which options and combination of options they select for any given roof type for comparison. It was considered that at a concept design stage, when sustainability is most greatly influenced, designers will not be as interested in the specification of specific products, but will be more interested in the general performance of a certain system or combination of systems. Therefore, the research has focused at this level. Additionally, much of the academic research is done at a system level, looking at the performance of systems rather than specific products. Typically products have datasheets that may or may not be certified by any external party, meaning that the validity of their performance claims can be questionable.

5.9 Conclusion

In summary, the overarching research philosophy is based on a pragmatic realist stance, and in doing so utilises both deductive positivistic approaches from the research of others and inductive ground up approaches. The overall research approach is that of action research combining a mixture of data collection methods. Methods used include workshops and questionnaires that were developed and implemented in collaboration with practitioners with reflection on their success as part of the action research approach.

Further explanation of different philosophical approaches to defining and practicing sustainability is covered in the literature review in Section 2.2.2 and has influenced the methodology to this research and the ontological, epistemological and axiological assumptions of this work. This section covers the broad overarching research approaches and strategies used. The individual methods used in each section are further explained in the respective sections and have been heavily influenced by stakeholder engagement and problem structuring methods, along with the MCDA techniques detailed in Section 4.

Part 1 utilises an overarching action research methodology to develop and test approaches to defining sustainability themes in the project context. It is intended that the emerging output can be used as a basis for sustainable decision making.

Part 2 of the research, first utilises an action research based case study to better understand the challenges of project decision making in the context of projects. Then it develop methods for bringing together roof performance information that is required in order to make more informed roof decisions. Then an approach is developed based on that of value focused thinking that can combine stakeholder opinions and values on what is important. Finally, these areas of work are synthesised through the development of an approach and accompanying decision support tool to inform sustainable roof selection.

Part 1: The development of approaches to engage stakeholders in defining sustainability and value for projects

6 Introduction to Part 1

In this part of the thesis an action research methodology is applied to develop and test approaches to engage stakeholders in defining sustainability and value for projects. This has been done through applying a range of methods whilst the researcher has worked in the sponsoring organisation. These methods have been applied through the action research process, which has broadly involved the following stages, (1) diagnosing, (2) planning, (3) taking action, (4) evaluating.

These are explained in more depth in the respective sections. These have been done for each case study in each section, but there has also been smaller, tighter learning loops involving dialogue with numerous people in the sponsoring organisation in order to develop the approaches and also receive feedback on their success from their perspective.

The aim of this part of the work was to trial and develop techniques that would allow stakeholders to better define what represents sustainability and value from their perspective. It builds up on the work reviewed in the literature and aims to address some of the current areas of future work with respect to defining sustainability considerations for building projects.

This section is primarily addressing research Question 1 as detailed in Section 5.2, which is as follows:

- Is it feasible to develop stakeholder participation techniques to engage project stakeholders in defining project sustainability and value themes on which to base design decisions that integrates:
    a. stakeholder values and preferences?
    b. environmental, social, and economic value?
    c. stakeholder knowledge, rather than considering purely expert knowledge?

These questions were addressed through two research objectives:

- To develop and test a set of stakeholder participation techniques to define sustainability themes for a project's context.
- To address the challenges of integrating sustainability into the design process in the building industry.

Section 7 develops a questionnaire based approach to understanding the values of project stakeholders building on previous work in the field. An action research process is initially undertaken within the sponsoring organisation through a combination of trial questionnaires, workshops, and dialogue with individuals, to test the acceptability of using the questionnaire with practitioners. Modifications based on feedback from practitioners are made to the questionnaire before it is trialled on a client facing project. The results output were considered positive by the project manager. The techniques were also presented to numerous other engineers within the sponsoring organisation with positive feedback on how they could help inform higher value design.

Section 8 develops a series of workshop based techniques to define the sustainability themes for projects based on stakeholder engagement literature. Two action research based case studies were undertaken to test the approaches, gaining feedback from participants and also through observation. This process was chosen, as it was thought that if the techniques were utilised in industry with practitioners, then the techniques would be much more likely to address the challenges of the design process as described in Section 2.3.3. The output of the results was also presented to over 50 individuals in the sponsoring organisation with opportunity to discuss the results afterwards. Feedback from practitioners was positive and informal feedback from the client was also positive on the approaches used.

Section 9 considers how the approaches address the research questions and objectives. The approaches developed and tested define broad project sustainability and value objectives. These objectives can feed into project decisions and also more detailed decisions on system and component selections for building elements such as roofs. Whilst the thrust of the overall research is considering roof selection, this part of the thesis is about defining what decision making criteria should be considered with respect to providing a sustainable building for a given context and in doing so defining the strategic project objectives. How the approaches developed relate to roof design are discussed in Part 2.

7 Part 1: Action Research Case Study 1A – The development of questionnaire to understand stakeholder values

7.1 Introduction

Section 2.3.2 of the literature review considers the importance of value in the construction industry and also the relationships between sustainability and value. It is based on the assumption that if sustainability choices are to be willingly taken on the project (not enforced through regulatory mechanisms) then sustainable options will have to be seen as good value in the eyes of the project's stakeholders.

Some argue that, "value delivery is the goal of all projects," (Austin et al., 2005b). However, what represents value? Many would argue that this is a design that best meets the requirements of the project, on time and on budget. However, often priorities and requirements are not made clear, additionally the requirement documentation may be unrealistic, or not represent the thoughts of the wider project stakeholders. These are issues that often leave designers asking, *'where should they focus their efforts to give true best value?'*

This is considered important, as literature identified in the review, outlined that value is often the key aim of construction projects (Austin et al., 2005b) and also that designers struggle to prove the value of design (Gann et al., 2003). There were also strong relationships between the six types of value defined by (CABE, 2007) and sustainability. These included consideration of the *"social"* and *"environmental"* value as well as consideration of the *"exchange"* and *"in-use"* value of the building and in doing so consideration of the building's life cycle. Therefore it was considered that if a clear definition of value to the stakeholders can be developed, then this can be used to provide the decision objectives to inform more sustainable choices and design development. Keeney (1992) advocates making values explicit as the first step in value focused thinking which has significantly influenced the approach to this research.

Additionally, value is rarely described in a project context**.** This is surprising given that it is this temporary environment that brings together organisations, disciplines and wider stakeholders with potentially divergent values systems and influences (Mills, Austin et al. 2009). The aim of this aspect of work was therefore to develop an approach to better understanding value and sustainability for the project as it is something which is not often discussed in the project context. In doing so it was addressing research question (1) how can sustainability and value be better defined for a project's context? Better here was to consider the success of the approaches developed through the action research process by reviewing the techniques against how they addressed gaps identified in the literature.

The overall approach to this was through undertaking action research to further develop and test techniques detailed in the literature for defining what represents value for a project with construction professionals and test this on an action research case study project. In doing so, it was considered that this will help ensure that the work was addressing question (2) what are the main challenges of the design process and how can these be overcome? Again success would be defined against how they addressed gaps in the literature.

The work considers value broadly with the emphasis on understanding environmental, social and economic value. This first involved understanding whether such approaches would be considered appropriate to use in the construction, and additionally whether they would first be acceptable to project stakeholders. Such understanding was achieved through utilising the values questionnaire within the sponsoring organisation and undertaking a number of internal surveys and follow up workshops to discuss the potential for use on projects. This was important in order to gain trust and also negotiate access to use the approach on a live project.

The preliminary internal work was used to refine a values based questionnaire based on the work of Schwartz (1992) and adapted for the construction industry by Mills et al. (2009), and add additional project specific questions. This was then tested on a case study project and followed up with a workshop with some of the stakeholders who responded to the questionnaire to assess whether the approach was useful in understanding what represented environmental, economic and social value for the project. The workshop also included application of another problem structuring method looking to understand the relationships between the project requirements and the values.

7.2 Background & context

This case study shows the application of a questionnaire aimed at understanding what represents value and sustainability for a pre-prep private school based in the South West UK. The project was a new-building project for children under seven years old (taken from project brief). The budget for the project was £2.35M. The research described in this report was conducted between October 2010 and February 2011. The project had some high sustainability aspirations and therefore aligned with the context of this research. The research was conducted at RIBA Stage D (see Figure 2—5), so had already gone through the concept stage of the project. Whilst ideally this would have been conducted earlier in the process to really understand the needs of the stakeholder and inform the project brief, this was a compromise that had to be made working on a real world project.

7.3 Action research process

The following action research process was undertaken on this particular piece of work

- Diagnosing
    - Literature review to identify potential techniques
    - Internal Trial of Schwartz Values Technique as a method to use in the industry
    - Follow up workshop to discuss results with practitioners
- Planning
    - Identification of potential client to trial approach on
    - Modification of survey based on feedback from workshop and dialogue with project manager to make the survey more project specific.
- Taking Action
    - Survey sent to case Study project stakeholders
    - Results from survey analysed and circulated to stakeholders in an pre-workshop information pack
- Evaluating
    - Case study project workshop to ask participants about how representative they felt the results were
    - Feedback from Client and Project Manager
    - Approach written up and presented at numerous workshops in the sponsoring organisation with opportunity to feedback on the process and results.

7.4 Methods

7.4.1 Theory and overall rational for choice of method

The questionnaire was chosen as a data collection method for the following reasons (Saunders et al., 2003):

- It allows the collection of a large amount of data from a population in a highly economical way
- The data collected is standardised and thus easy to process and analyse.

Additionally, values are difficult to express in a group based environment (with strong-minded individuals), where quick consensus is important (Mills et al., 2009). Therefore, the questionnaire was also considered appropriate in this particular context as a method of eliciting a wide range of opinions for discussion in a workshop. It offers the advantage that stakeholders can give their opinions anonymously, without politics or power structures coming in to play.

However, it was considered that a questionnaire alone wouldn't facilitate the depth of understanding and development of how to progress. Thus, it was considered that this should be the first step in a multi-method approach. This is recommended by (Saunders et al., 2003, Aldridge and Levine, 2001) as a means of triangulation.

Additionally, as a longitudinal study it was considered that the results of the questionnaire, when analysed prior to the workshop would provide a 'boundary object' around which value can be discussed (Whyte and Lobo, 2010). Boundary objects are defined as (Star and Griesemer, 1989):

> *"objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual-site use. They may be abstract or concrete. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is key in developing and maintaining coherence across intersecting social worlds."*

Boundary objects are said to allow coordination without consensus as they can allow an actor's local understanding to be reframed in the context of some wider collective activity (Bechky, 2003). In this case, the survey results act as a boundary object as they explicitly state a set of results openly and allow a common understanding to be developed. They also allow opinions to be openly stated without people having to state their own position which can reduce conflict. This aspect is also considered important to gain a mutual understanding of what represents value and also collectively learn of potential conflicts between stakeholder groups. It was considered that whilst the questionnaires could provide trends and understand differences of opinion the level of understanding behind why these trends or differences of opinions might arise would not be able to be explored through the questionnaire approach alone. Additionally, this would not provide an appropriate mechanism on how the design could be progressed. Therefore a workshop was also developed and facilitated to capture these elements. Whilst the questionnaire could potentially be circulated to a large number of people to gain broad opinion, a workshop with a large number of people would be difficult to facilitate.

7.4.2 The questionnaire

The client representative was presented with an overview of the approach and the potential benefits of undertaking a values survey and follow up workshop. Benefits of engaging stakeholders with respect to value were taken from the literature and summarised in this proposal along with some of the techniques that could be used. This was then discussed in a meeting prior to the circulation of the values survey based on that of (Schwartz and Mark, 1992) but with additional project specific questions. It should be noted that the Schwartz Values Survey (SVS) was modified for the construction industry by Austin et al. (2005b) and is also discussed in Mills et al. (2009) and Mills et al. (2006). The specific aspects considered for the survey approach are outlined below. However, this was further refined to include project specific questions. This is discussed below.

7.4.2.1 Designing the questionnaire

This approach builds upon techniques highlighted from a comprehensive and cross disciplinary review of the literature, and further developed through consultation with industry professionals from within the sponsoring organisation and its sister company Happold Consulting as part of the Action Research methodology. During this exercise, the Schwartz Values Survey (Schwartz and Mark, 1992) as modified for the construction industry by Mills et al. (2009) was used as the basis to understanding stakeholder values and whether capturing these would be useful in the construction environment. This was trialled internally within the sponsoring organisation and through follow up workshop sessions. There were some concerns about the time it would take project stakeholders to complete the survey and how they would react to the questions. Additionally, the questions were focused around human values and were seen by some as being very removed from the building and design process. Therefore the survey was reduced in size and thus some of the validity of the Schwartz Values Survey, which has been tested extensively, is likely to have been lost. The survey was condensed from 56 to 40 questions relating to values. However, questions from each of the broader 10 categories of the survey still remained.

It was suggested at the workshops that additional questions that were more focused on the project and its particular context would also be beneficial. A further 18 questions were asked directly in relation to project requirements of the pre-prep school. The survey used is included in Appendix L. The survey questions were identified and formulated upon analysis and dissection of the project brief, which included the requirements for the project. These were then reviewed by the lead project manager to ensure that they represented the project brief as was currently understood at the time. The time to complete the survey remained at 20-25 minutes and the project specific survey, was trialled by the project manager and the school bursar. It was considered that the modifications would give the survey a more context specific angle whilst still capturing an adequately wide spectrum of the Schwartz Values Survey. The questions were predominantly closed questions asking for users to rate the importance of different values/requirements as described in the questionnaire based on that of Schwartz with the same structure and use of a 9 point scale which ranged from -1 to 7. Stakeholders were encouraged to use the full range of ratings. Closed questions were selected based on those that had been successfully validated through the Schwartz approach, and also to ease the analysis which would potentially have to be done on a considerable number of people prior to the workshop.

Whilst the survey was anonymous, stakeholders were asked to input some data so that the group of stakeholders that they associated most closely with was evident. This was achieved through asking the question, *“Please select which stakeholder group best describes your relationship with the [Pre-Prep School].”* This question was accompanied by a list of options, which reflected those of the main groups which the survey was intended to be circulated to (as described in the next section), along with ‘other’ as an additional option.

Two open questions were also asked in the questionnaire. These included a question aimed at understanding if any important requirements for the project had been left out and a further comments box where users could leave any other feedback they felt appropriate. The work that the survey was based upon was acknowledged through referencing this at end of the survey. A copy of the questionnaire used is included in Appendix F.

7.4.2.2 Selecting the survey sample

The survey sample was selected to be those stakeholders involved in the case study project. These were identified as the following stakeholder groups; management, design team, teaching staff, local residents, governors, and parents by the project manager and the school bursar.

7.4.2.3 Administering the questionnaire

Access to the sample of stakeholders was agreed in principle in an initial meeting with the school’s bursar who was managing the project from the ‘client’ side. However, in the interests of openness the bursar and project architect were both asked permission before the survey was circulated.

The questionnaire was administered in two forms; web-based and a paper-based form. The web-based questionnaire utilised a web-site called “Survey Monkey”. The web-based survey was introduced by an email from the project manager containing a link to the survey. This included the survey’s purpose, time estimated to complete, deadline for completion. Also included was the different stakeholder groups that the survey would be distributed to, along with the contact details and name of the researcher who had developed the approach so that they could contact him if they had any questions. The paper based questionnaire was introduced verbally upon being given to the intended respondents. The project manager contacted the design team directly. With respect to circulating to governors and pre-prep staff, the school’s bursar took the responsibility of forwarding this on to these stakeholder groups. It was hoped that such an approach would improve the response rate, as they would have been receiving the survey from someone that they knew.

In addition to the email explaining the purpose of the survey, both web-based and paper-based versions had a cover sheet which included; the intended purpose of the survey; instructions to follow to complete the survey; and a statement stating that their survey results would remain anonymous.

The circulation method encouraged people to forward on to relevant parties that had not been included on the original circulation therefore the response rates were not able to be calculated. However, the survey was not intending to do any significant statistical analysis and make inferences about the entire population so this was not considered important.

7.5 Results

7.5.1 Questionnaire

The data from the questionnaire was analysed prior to the workshop. This included initially filtering the responses to ensure that the questionnaires had been filled in correctly. For example respondents that had not filled in more than 41 of the questions were removed. Additionally, those who were considered not to have used the range of answer options appropriately were also removed. The reason for this is that one of the five recognised features of values is that they *“can be ordered by relative importance and so form a system of value priorities that characterise cultures and individuals”* (Schwartz and Mark, 1992). If all values are of the same importance then their usefulness in making decisions is negligible. For example if all values are of the same importance (whether high or low), then decisions in relation to those values should all be approximately equal in desirability.

With respect to the questionnaire, 31 people responded to the survey. Of these 26 stakeholders responded to the survey according to the instructions, 5 responses were filtered out where there had been no attempt to use a range of values across the scale. These were classed as results where the average was above 5 or below 2. Of the appropriate responses 17 were via the internet based survey monkey and 9 were via the paper based questionnaires. As already discussed it was not possible to calculate the response rate due to the distribution method. However, it is important to consider that the opinions of so many peoples' priorities would not have likely been captured through traditional approaches. Figure 7—1 shows the range of people completing the survey correctly.

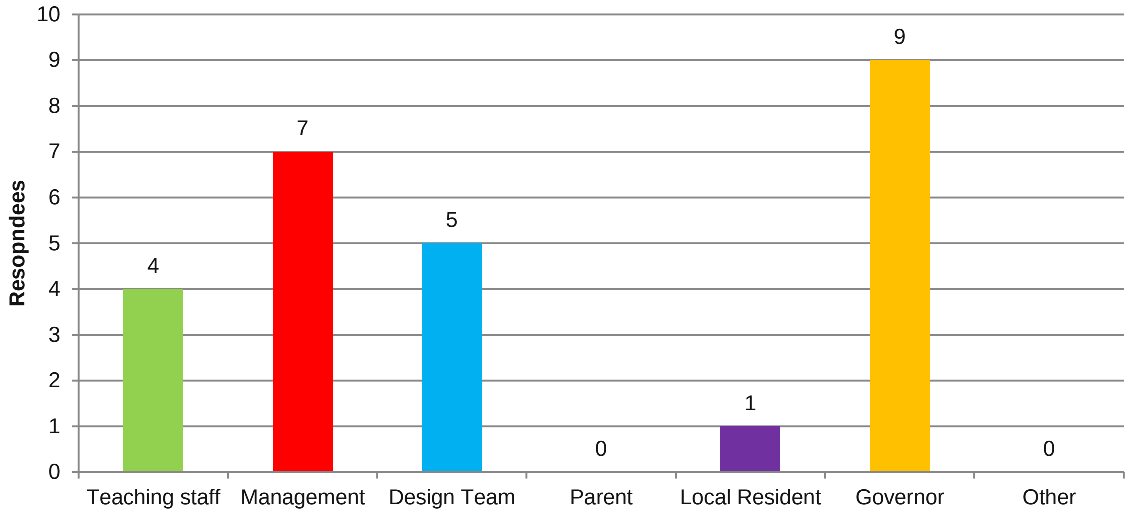


Figure 7—1 Respondents to survey according to profession

Figure 7—2, Figure 7—4 and Figure 7—5 show some of the resulting output and analysis from the initial stage of the process and approach outlined above. With respect to the survey distributed amongst stakeholder groups, responses were achieved from 7 of the management team, 4 teachers, 9 governors and 5 design team members and 1 local resident. This shows a much wider perspective than is typically achieved in a design situation. Figure 7—2 shows the individual stakeholder values and how through simple averages, a project culture can be defined. Standard deviations were also conducted to show the disagreement amongst stakeholders. The project brief had a strong sustainability theme however, Figure 7—2 shows the stakeholder values related to, *"protecting the environment"* and *"unity with nature"* were not high scoring values. This provided a discussion point in the workshop.

Figure 7—2 shows a radar chart of the values of the stakeholders who completed the questionnaire. Each coloured line represents a different stakeholders set of values This was presented during the introduction to the results to highlight that people have different value sets and as this informs their judgement of value, it is a very personal and subjective construct. To provide clarity and understand the culture of the teams, the averages were plotted for the group as a whole. In addition to this the averages were also shown for each profession. Trends can be shown through plotting the averages and standard deviations for the data. These were presented for discussion at the workshop.

Figure 7—3 shows the results for the different stakeholders for each value set in a Table format.

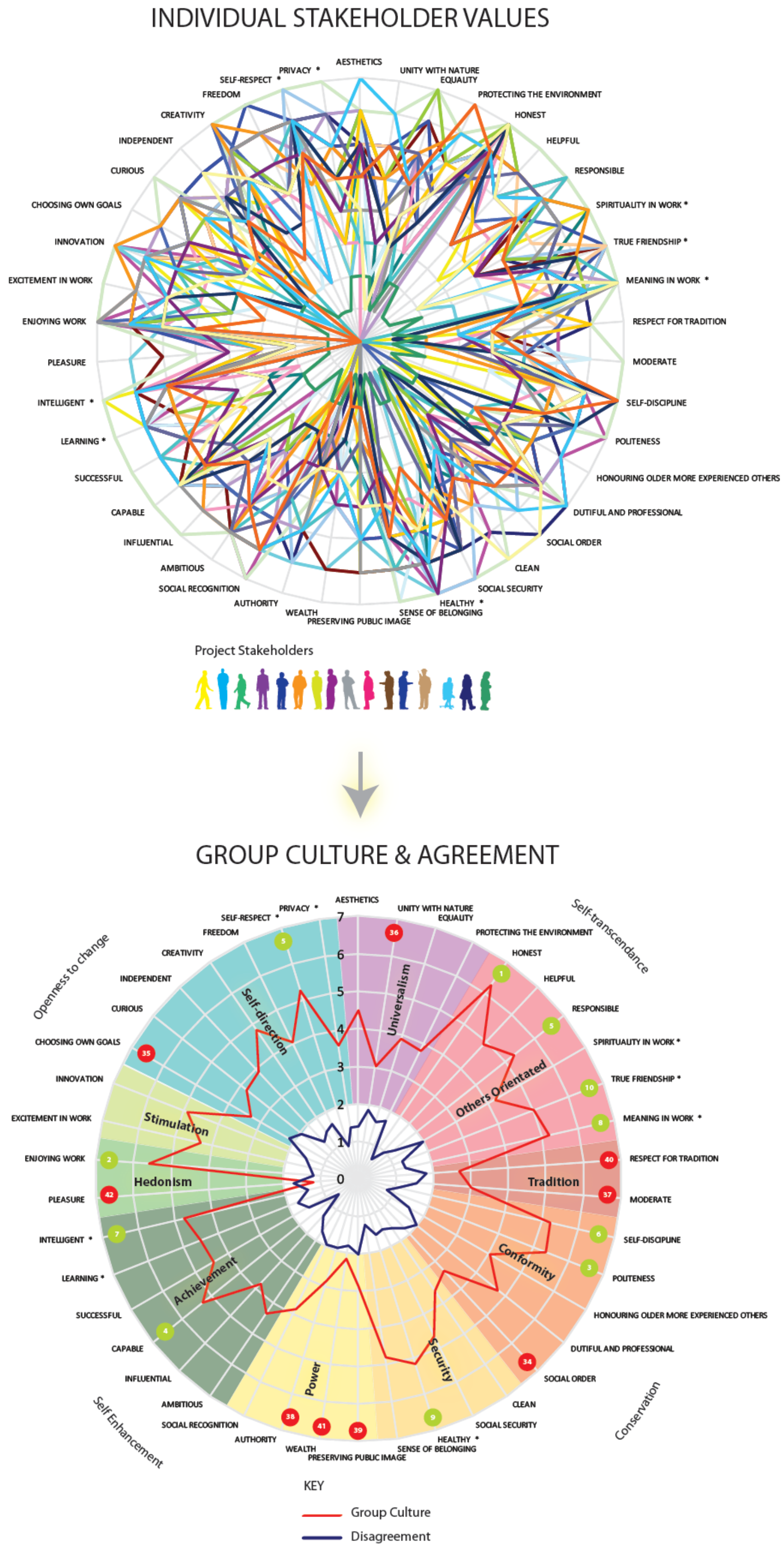


Figure 7—2 Results from values survey conducted before workshop[4]

[4] In the top image each coloured line represents a different stakeholder. In the lower image the red lines represent the averages across stakeholders and are taken to simplistically represent group culture. The blue line represents the standard deviation and is shown to represent disagreement.

VALUE SET	VALUE description	AVERAGE SCORE	AVERAGE RANK	STANDARD DEVIATION SCORE	STANDARD DEVIATION RANK
UNIVERSALISM	**AESTHETICS** *a pleasing visual appearance, the beauty of nature and the arts*	4.5	18	1.40	17
	UNITY WITH NATURE *fitting into nature*	3.1	36	1.85	35
	EQUALITY *equal opportunity for all at work*	3.9	26	1.59	25
	PROTECTING THE ENVIRONMENT *preserving nature*	3.8	29	1.70	29
OTHERS ORIENTATED	**HONEST** *genuine, sincere*	6.3	1	0.64	1
	HELPFUL *working for the welfare of others by giving them just reward*	4.9	11	0.97	5
	RESPONSIBLE *dependable, reliable*	5.3	4	1.22	8
	SPIRITUALITY IN WORK * *emphasizing soulful matters rather than material matters*	4.2	23	1.99	40
	TRUE FRIENDSHIP * *close, supportive friends, love*	5.0	10	1.26	10
	MEANING IN WORK * *purposeful work*	5.2	8	1.28	11
TRADITION	**RESPECT FOR TRADITION** *preservation of time-honoured customs*	2.7	40	1.81	34
	MODERATE *avoiding extremes of feeling and action*	3.0	37	1.56	23
CONFORMITY	**SELF-DISCIPLINE** *adherence to one's own voluntary codes of practice, self-restraint, resistance to temptation*	5.3	6	1.07	6
	POLITENESS *(courtesy, good manners)*	5.4	3	0.81	3
	HONOURING OLDER MORE EXPERIENCED OTHERS *showing respect*	4.1	24	1.54	22
	DUTIFUL AND PROFESSIONAL *meeting obligations, obedient, adhering to statutory codes of practice and legislations*	4.8	15	1.97	39
	SOCIAL ORDER *stability of a group e.g. project group or local community group*	3.4	34	1.79	33
SECURITY	**CLEAN** *neat, tidy*	3.6	32	1.60	26
	SOCIAL SECURITY *protection of a wide group of people to include their financial, physical and mental well-being*	4.7	17	1.50	18
	HEALTHY * *not being sick physically or mentally*	5.2	9	1.57	24
	SENSE OF BELONGING * *feeling that others care about oneself*	4.8	13	1.24	9
POWER	**PRESERVING PUBLIC IMAGE** *protecting "face"*	2.9	38	2.01	41
	WEALTH *material possessions, money*	2.2	41	1.79	32
	AUTHORITY *the right to lead or command*	2.9	38	1.93	36
	SOCIAL RECOGNITION *respect, approval by others*	3.9	28	1.95	38
ACHIEVEMENT	**AMBITIOUS** *hard-working, aspiring*	4.4	21	1.69	28
	INFLUENTIAL *having an impact on people and events*	3.8	29	1.36	14
	CAPABLE *competent, efficient and effective*	5.3	4	0.66	2
	SUCCESSFUL *achieving goals*	4.5	20	1.50	19
	LEARNING * *enjoying the opportunity to learn, improve skills and learn new skills*	4.5	18	1.73	30
	INTELLIGENT * *logical, thinking*	4.8	15	1.37	15
HEDONISM	**PLEASURE** *gratification of desires and indulging oneself*	1.2	42	1.74	31
	ENJOYING WORK *find reward in work activities, relationships, making a contribution and having a friendly atmosphere*	5.6	2	1.19	7
STIMULATION	**EXCITEMENT IN WORK** *stimulating experiences*	4.3	22	1.30	12
	INNOVATION *varied work filled with thought, challenge, novelty and change*	4.9	11	1.52	21
SELF-DIRECTION	**CHOOSING OWN GOALS** *selecting one's own purposes*	3.3	35	2.13	42
	CURIOUS *interested in everything, exploring*	3.8	29	1.94	37
	INDEPENDENT *self-reliant, self-sufficient*	3.9	26	1.33	13
	CREATIVITY *uniqueness, imagination*	4.8	13	1.51	20
	FREEDOM *choosing one's own approach*	4.1	24	1.61	27
	SELF-RESPECT * *belief in one's own worth*	5.3	6	0.91	4
	PRIVACY * *the right to have a private sphere*	3.6	32	1.39	16

Figure 7—3 Average and standard deviation results for all stakeholders including ranks.

Figure 7—2 and Figure 7—3 show the values across groups. The analysis also highlighted the top and bottom 10 scoring values to demonstrate priorities for the project. Interestingly, whilst much of the brief was aspirational with respect to sustainability considerations, as shown in Figure 7—4 with requirements such as, *"be energy efficient and be environmentally designed,"* and, *"make the most of natural resources,"* values such as, "*protecting the environment"* and *"unity with nature"*, were collectively relatively low scoring values scoring 29/42 and 35/42 respectively. This allowed these issues to be relayed back to them, and also highlighted to the design team, that if this was the case then providing an environmentally designed building may not necessarily be seen as good value by the stakeholders of the project.

Figure 7—4 shows the average scores and ranking of different requirements by the stakeholder groups, again this showed the agreement of diversity of opinion and captured this explicitly.

REQUIREMENT	AVERAGE						RANK					
	MANAGEMENT	TEACHING STAFF	GOVERNOR	DESIGN TEAM	LOCAL RESIDENT	ALL	MANAGEMENT	TEACHING STAFF	GOVERNOR	DESIGN TEAM	LOCAL RESIDENT	ALL
1 Offer MORE SPACE (larger classrooms)	3.3	5.3	5.1	3.5	3.0	**4.3**	15	3	5	13	14	11
2 Offer DEDICATED SPECIALIST ROOMS (ICT Suite, Art Room, Library, Shower Room, Food Tech)	4.5	4.3	4.4	3.0	3.0	**4.0**	8	14	14	15	14	16
3 Be ENERGY EFFICENT and be ENVIRONMENTALLY DESIGNED	4.8	4.8	5.4	4.5	5.0	**5.0**	7	8	3	7	5	5
4 Be ATTRACTIVE and AIRY offering views for all	4.5	4.8	4.9	4.8	4.5	**4.7**	8	8	6	6	9	8
5 Have DIRECT ACCESS TO OUTDOORS from all classrooms	3.8	4.0	4.0	5.0	4.5	**4.2**	13	15	16	1	9	12
6 Be a PRACTICAL AND PRAGMATIC building with FLEXIBILITY for future changes, development and potential expansion	5.5	5.0	5.9	4.0	7.0	**5.4**	2	5	1	11	1	1
7 Have a CREATIVE FLAIR and a MEMORABLE DESIGN	4.5	4.8	4.8	4.5	5.0	**4.7**	8	8	8	7	5	9
8 Have a GARDEN AREA for pupils to grow plants/vegetables	5.3	5.0	3.5	5.0	4.5	**4.5**	4	5	17	1	9	10
9 Have a MODERN IT NETWORK and WWW. CONNECTIVITY	4.3	4.5	4.1	3.0	5.0	**4.1**	11	12	15	15	5	14
10 Be EASY and COST EFFECTIVE to MAINTAIN	5.3	4.8	5.3	5.0	6.0	**5.2**	4	8	4	1	3	3
11 Incorporate STATE OF THE ART building TECHNOLOGIES	3.0	2.0	4.8	2.8	3.0	**3.4**	16	18	8	17	14	17
12 Utilise and DEMONSTRATE SUSTAINABLE USE OF MATERIALS	3.8	3.5	4.9	3.5	4.5	**4.1**	13	17	6	13	9	13
13 Be in KEEPING WITH ITS SETTING	6.0	4.5	4.8	5.0	5.0	**5.0**	1	12	8	1	5	4
14 MAKE THE MOST OF NATURAL RESOURCES (sun/shade, orientation, wind and views)	5.5	5.0	5.6	5.0	4.5	**5.3**	2	5	2	1	9	2
15 NOT DATE WITH TIME	5.0	5.7	4.6	4.5	5.5	**4.9**	6	1	11	7	4	6
16 Have a CLEAR SEPERATION OF WET AND DRY AREAS	2.0	4.0	3.1	2.3	3.0	**2.9**	18	15	18	18	14	18
17 Offer SUITABLE STORAGE FACILITIES to provide ready access in classrooms	2.3	5.5	4.6	3.8	3.0	**4.0**	17	2	11	12	14	15
18 Have LOW RUNNING COSTS AND BE ECONOMICALLY VIABLE	4.3	5.3	4.6	4.5	6.5	**4.8**	11	3	11	7	2	7

Figure 7—4 Requirements ranking table[5]

[5] a score of 1 represents the most important ranks

Key areas of discrepancy are shown in requirements 1, 5, 6, 8, 17. With respect to requirement 1, management placed this as a relatively low scoring requirement in terms of importance. However, this was a high scoring requirement amongst teaching staff. Additionally, the design team considered requirement 5, *“have direct access to outdoors for all classrooms,”* and requirement 8, *“have a garden area for pupils to grow plants/vegetables”* to be key priorities and this was not necessarily shared across the wider stakeholders. In the dialogue that emerged in the workshop, this was seen as a priority for regulatory reasons, but this may not necessarily have been explained without what the results showed. The practical and pragmatic building was seen to be a high priority across all stakeholder groups except the design team. Requirement 17, relating to storage space, was also considered to be a key priority for teaching staff, but a relatively low priority for the management team, thus highlighting a possible area of divergence. When this was discussed in the workshop, it was considered that there was a strong relationship to the desire for more space as defined in requirement 1. This was highlighted utilising the relationship mapping, and example of which is shown in Figure 7—5. Figure 7—4 shows that the design team was not necessarily focusing on requirements considered of value to the stakeholders. It also provides a potential way of ranking the requirements on a project and thus demonstrating where the design team should focus more effort.

A workshop was then structured to allow stakeholders to feedback and discuss the results. A short summary of the results was circulated prior to the workshop in a brief 4 page document to allow stakeholders the opportunity to consider the results prior to the workshop. A workshop was then held so that the stakeholders would be involved in the dialogue and be able to discuss the results and outline ways in which they thought the project should progress to represent high value design. This method and rational for the workshop is described in the next section.

7.5.2 Workshop

The results were presented back in a workshop as the approach:

- Allowed two way dialogue and the opportunity to ask questions
- Encouraged group learning and also group involvement in defining what was important to the project
- Establish trust between the researcher and wider stakeholders

The workshop was not recorded and transcribed as it was thought that this may impact on the intended open and honest nature of the discussion. Plus with some of the techniques that were used, such as discussing and brainstorming opportunities for value in pairs, based loosely on a technique called speedstorming (Joyce et al., 2010), made it difficult to record the individual conversations.

The main agenda items for the workshop were as follows and had to be conducted within an afternoon session and thus time was limited. The main facilitated sessions are described in more depth below.

- **Introduction and purpose:** This involved introducing the purpose of the workshop and reiterating why people were there. The researcher was introduced to the workshop team along with a brief background of his research. The introduction was also there to establish an open nature and informal format. It was stressed that we were interested in their opinions and that there were no ‘right’ or ‘wrong’ answers.
- **Background to values and value:** This involved a quick overview of the theory so that the attendees were assured of the rigor of the approach and also how their values and questionnaire responses related to the project at hand. It highlighted different notions of the measurement of value from the objective to the subjective and how people judge things differently based upon their values and beliefs.
- **Introduction to value survey and overview of results:** This was followed by an introduction to the survey and how it had been formulated by Schwartz originally and how this had been modified to include project related questions as well by the researcher. Their results along with points of agreement were explained to the workshop participants.
- **Open discussion of the value survey results:** This was followed by an opportunity for discussion across the group. Areas which were surprising were encouraged to be discussed, along with the reasons for different scores
- **Explanation of how the results can be applied:** This showed how the results could potentially be used to prioritise project budget and effort and how they could potentially be used to develop a value framework for the project.

- **Relationship mapping:** Simple relationship mapping diagrams were also developed to show relationships between requirements and how sustainability requirements could align to provide potential ‘win-wins’ across requirements and ‘possible conflicts’ between requirements and sustainability related issues. This then allows the client to think about sustainability in relation to what is important to them and also relate these to their stakeholders’ values made explicit through the values survey and ranked requirements. This is shown in Figure 7—5. Requirements are shown in grey boxes and values in italics. This was used to inform the dialogue and generate a better understanding amongst stakeholders.

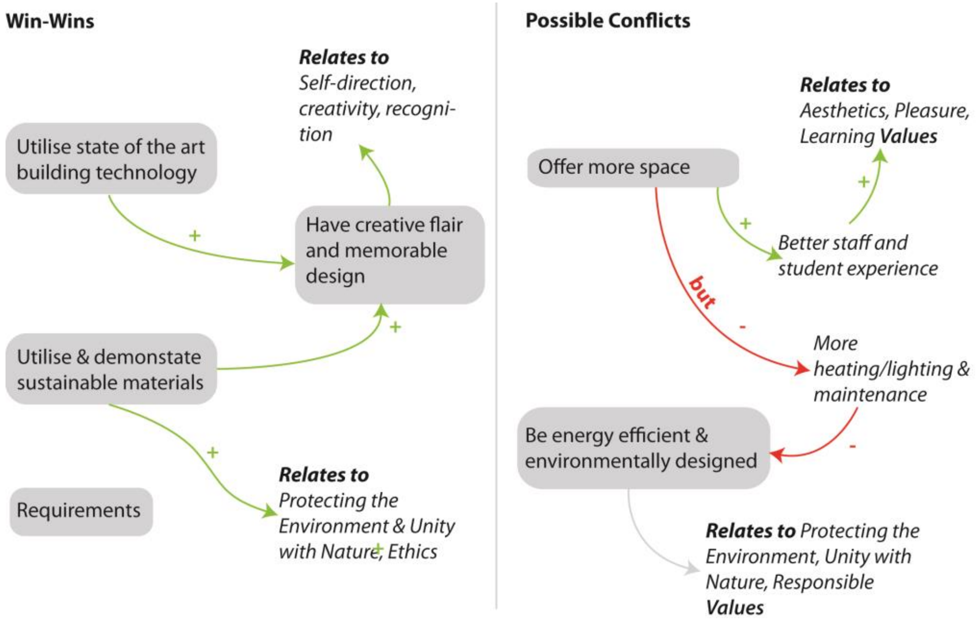


Figure 7—5 A mapping approach to simply show the relationships between requirements

7.6 Discussion

In summary an action research based approach was undertaken to develop and test an approach to better understand what value represented for a client. This involved the following action research steps.

1. Literature review to identify potential techniques
2. Internal Trial of Schwartz Values Technique as a method to use in the industry
3. Follow up workshop to discuss results with practitioners
4. Identification of potential client to trial approach on
5. Modification of survey based on feedback from workshop and dialogue with project manager to make the survey more project specific.

6. Survey sent to case study project stakeholders
7. Results from survey analysed and circulated to stakeholders in a pre-workshop information pack
8. Case study project workshop to ask participants about how representative they felt the results were
9. Feedback from Client and Project Manager
10. Approach written up and presented at numerous workshops in the sponsoring organisation with opportunity to feedback on process and results.

It is understood that this is the first action research based approach to the development and testing of a questionnaire to understand client value in the construction setting. It is considered that this approach helps to better understand a group’s values and subsequently culture. Mills et al. (2006) argue that the Schwartz Values Survey approach to capturing and communicating values has been proved at revealing the core cultural aspects of organisations. Despite this, there were concerns that it could be considered too high level by some members of the sponsoring organisation, when trialling this prior to use on the school project. A survey was therefore developed partially based on techniques found in the literature and applied in the context of a pre-prep school building. Parts of the survey drew heavily on the Schwartz Values Survey (Schwartz and Mark, 1992) and also on the VALiD approach (Austin et al., 2005a, Austin et al., 2005b, Mills et al., 2006, Mills et al., 2009). However, the values part of the survey was reduced slightly in length by removing some questions, although care was taken to keep some questions from each of the broader 10 value sets as defined by Schwartz. This allowed space to complement the values questions with a bespoke survey section. These questions were based on the requirements of the brief. The results of the overall survey therefore gave an understanding of the overarching values of the stakeholders and also information on the opinions of the stakeholders in relation to project requirements.

Accompanying the Schwartz Values Survey questions with project specific survey questions also allowed users to score the importance of requirements to the project and it was considered that this was useful in highlighting differences of opinion across stakeholders and informing the dialogue of the workshop. The results could be talked about openly, without people criticising people for their opinions as their opinions were encapsulated within the results. Upon reflection the researcher considered that the results as presented also form a good boundary object around which open dialogue could proceed. The survey based approach is also considered a useful way to get the opinions of many stakeholders on their values and also their priorities for the project in terms of project requirements as it allowed many people to feed in and an analysis to be done relatively quickly and cheaply as the information was received in a codified manner. Additionally unlike workshops, trained facilitators are not as important.

Stakeholders were asked to add any requirements that they considered important that were not included in the list of questions relating to requirements in an open-ended reply box towards the end of the survey. However, the format of the survey did not encourage stakeholders to state explicitly what was important to them from a value perspective. It asked closed questions to stakeholders primarily to rate a set of pre-determined values or from the requirements outlined in the brief. Open ended questions were not well answered and answers that were given were short. Additionally, without having face to face contact and detail why the survey was important, it was felt that stakeholders would not invest the time to complete large numbers of open-ended questions. This is also detailed as a common feature of questionnaires in Saunders et al. (2003). Questionnaires tend to be better for descriptive research to identify different phenomena. However, they do not provide the best method of understanding the relationships between variables or understanding why a particular issue is important. Therefore due to the limitations of a survey based approach, the survey was followed up by a workshop to discuss the survey. The survey results were analysed and presented back to the stakeholders by circulating a short results paper prior to the workshop.

A 2 hour workshop was then held to discuss the results. This was structured to first present back the results, then have an open discussion on whether the results were appropriate, before finally considering the relationships between some of the results. Unfortunately none of the governors were able to attend the workshop.

Stakeholders were initially asked whether the survey was clear and of an appropriate length. Some concerns were raised by stakeholders around them not being clear on the reason why they were doing the survey. This is despite an introduction to the survey on the cover page. Some members of the stakeholder group stated at the workshop that it would be good to have an introductory session prior to receiving the questionnaire. However, there was general agreement that the survey was an appropriate length.

When discussing the results, there were general agreement that the results represented the opinions of the attendees. However, some of the results with respect to the Schwartz Values Survey which was modified for the construction industry as part of the Value in Design (VALiD) work (Austin et al., 2005b) were attributed to poor language for the context. For example, the *“pleasure”* value, described as *“gratification of one’s desires and indulging oneself,”* got the lowest score because of the way it was described according to many participants. Not because the value itself is not important to them.

With respect to the requirements of the school a member of the design team commented that it was a regulation relating to having direct access to outdoors from the classroom, that persuaded them to consider the requirement, *“Have direct access to outdoors from all classrooms,”* as a high priority rather than particularly the needs of the project. The workshop allowed the reason for this to surface and demonstrated how the survey can be useful in understanding the different perspectives across stakeholder groups if the results are explored in a workshop.

Considering the relationships between requirements through simple relationship mapping in the workshop was considered a useful exercise by the participants and the project manager. Such qualitative high level mapping of the relationships between criteria offer a useful starting point for dialogue and could potentially be useful in demonstrating how some design options could help achieve several requirements at once. Furthermore, such work can be tied back to the values identified as important (or not) to the stakeholder group through the values survey as shown in Figure 7—5 and also show how these relate to the broader values of the project stakeholders. Additionally, this showed visually that trade-offs may be required in some areas, and that it may not be possible to "have it all". However, some requirements had positive relationships, for example, there was debate between requirement 1, *"Offer more space (larger classrooms)"* and requirement 17, *"Offer suitable storage facilities to provide ready access in classrooms."* These two requirements were ranked the 3rd and 2nd most important requirements respectively by the teaching staff. This raised the question of whether providing suitable storage facilities may actually mean that smaller classroom spaces would be acceptable. This would have positive implications in terms of reducing construction costs and potentially reducing energy use, and maintenance and cleaning requirements. Thus looking at the relationships between requirements has benefits from a sustainability perspective.

The head of the school, commented that he considered the process worthwhile and would undertake such techniques on future projects as and when they occurred. Additionally, the bursar stated that the results were very interesting and that they would like the raw data as they felt that this could help them improve their decision making processes.

The approaches have been extensively presented and discussed in the sponsoring organisation, with many experienced engineers and practitioners saying how useful the approaches and associated results would be to them when considering project design and decision making.

It is considered that the benefits of the approach are:

- a survey based approach allows a large amount of information from lots of people to be collected and analysed quickly.
- a wide range of stakeholders have a say in informing what they think is important for a project.
- the results can be presented transparently and these values and scored requirements provide a boundary object around which dialogue can proceed.
- the results when discussed in a workshop could provide a good method of prioritising the project's objectives.

- A project's objectives can be considered in parallel to the high level values of the stakeholders, which may also help understand which are considered most important.
- Relationship mapping can be useful in identifying potential win-wins and also possible conflicts.

Limitations to the values based questionnaire and follow up workshops presented in this case study are discussed in the next section.

7.7 Limitations and further work

One significant and notable omission from the stakeholders engaged was the school children that will attend the completed pre-prep school. Due to their age it was assumed that the questionnaire would have not been well understood and consequently would have been an inappropriate way of engaging this set of stakeholders. This is undoubtedly a limitation of applying such methods and raises questions regarding suitable methods to use to engage the young, and other stakeholder groups that are unable to partake through using the tools detailed here in order to ensure they are not marginalised through the process. This is a broad and wide reaching research question for the design and construction industry and would represent an area worthy of future work.

Other limitations include that the bespoke part of the questionnaire was developed around the requirements of the brief, however it should be noted that the brief may be in flux at the early project stages and in some cases may not be well formulated or even formulated at all. Thus structuring questions relating to requirements of the brief may be difficult in cases where the brief is not well developed.

It was also considered necessary to develop the results of the workshop into a sustainability and value framework that can be used to inform decision making. This was not done for this project, as the project was put on hold shortly after this workshop. However, it is considered of importance to define the high level themes of such a value framework. Whilst the most important requirements identified by the stakeholder groups through the survey could be used to prioritise efforts, there was not significant opportunity for stakeholders to define other requirements that were important to them.

In terms of developing a value framework, both the DQI and the VALiD approach provides a set of pre-determined criteria, in the case of VALiD a list of 239 different criteria have been developed, which are organised according to the groupings of the DQI. Originally 118 criteria were identified by industry experts, this was later increased to 239 to reflect educational projects and a particular project culture. This suggests that to define the most appropriate criteria for a project, you need to consider this on a project by project basis. Additionally, whilst the author appreciates that a list can be a useful checklist, this is a large set of value criteria which could potentially overwhelm the stakeholders including the design team. Additionally, checks should be done to consider the overlap between such criteria and whether some are in fact double counting. This is not problematic with the Schwartz Values Survey as the Schwartz Value Continuum has been shown that the 10 basic value sets are discriminated in all societies (Schwartz and Boehnke, 2004).

Therefore, further work was considered necessary to develop an approach to allow stakeholders to define requirements in relation to sustainability and value. In contrast to the primarily deductive approach of surveys, it was considered that an inductive approach to defining value may be useful for the project. This is the approach that is presented through the following case studies. It is considered that open questions are required and therefore a survey based approach may not be the best way to achieve the appropriate input from stakeholders. Therefore a workshop based approach to doing this is considered through the next two case studies.

Additionally, further work should seek how such approaches could be better integrated into the design process. For example, there was some resistance from a member of the design team to using the approach. This could be because they felt threatened by the approaches and that they may be used to judge their design. It should be noted that none of the work deals with the politics of the project arena and further work regarding how to address such issues would be beneficial.

7.8 Conclusion

This section develops an approach to better understand the values of stakeholders within the project context through the development of a questionnaire to identify what they value through an action research based approach. It combines elements of the Schwartz Values Survey with more project specific requirements. Thus providing an overview of the groups high levels values and also information on what they consider important with respect to requirements taken from the project brief. The survey was discussed in a follow up workshop with stakeholders and was considered useful by the attendees. The next section considers alternative ways to engaging stakeholders through workshop techniques aimed at understand what represents sustainability from their perspective.

8 Part 1: Action Research Case Studies 1B and 1C – The development of workshop techniques to understand stakeholders' perspectives on sustainability

8.1 Introduction

This section considers the development and application of a set of approaches intended to be used to better define sustainability within the context of a particular project. The approaches developed are tested through action research in workshops to define sustainability and value themes for a project. These are discussed together in this section, as the approaches used in both situations were relatively similar.

In doing so it was considered that the techniques employed to do this, would be addressing areas of weakness with current building environmental/sustainability assessment tools as summarised at the end of the literature review in Section 2.4 and thus answering the research questions defined in Section 5.2.

8.2 Background and context

8.2.1 Action Research Case Study 1B: large scale university refurbishment project

This project involves the refurbishment of a 15,000m^2 (Gross Floor Area) university building, designed in the late 1960s and constructed early in the 1970s. The building contained lecture theatres, labs, teaching space and a museum area. Future uses involve bringing together the stakeholders from many different environmental institutions to work in the building as well as improving the museum space. The building pre-dates lots of the UK's current building regulations relating to thermal performance and structural stability. The aims of the project were to undertake a major refurbishment to provide modern spaces for the museum, department of zoology, lecture theatre, offices and shared facilities. The work was conducted in May 2012. The work described in this section was conducted at RIBA Stage C.

It should be noted that the University was interested in the approach to defining value for the project that was described in the bid (that was based on the work of Case Study 1A). This used the work outlined to explain the approach and was according to one of the project managers, one of the reasons that the team was commissioned to do the project.

There was also a desire for the building to be ‘sustainable’ and to reflect stakeholder needs. Therefore this work summarises the development and understanding of stakeholder wants and needs from a sustainability and value perspective. It outlines processes that were used in capturing their opinions. The purpose of this piece of research was to engage and capture stakeholder opinions so that this could be made into a bespoke sustainability framework. Novel methods and techniques were trialled in the stakeholder environment and the output of applying these techniques are shown along with some preliminary feedback.

The purpose of this workshop was to understand the stakeholder perspectives on sustainability in relation to the building. The workshop was an opportunity to help the design team understand the stakeholders’ opinions on what is important from a sustainability perspective and also learn more about what the different stakeholder groups do and how they work. It was also an opportunity to understand the barriers from the stakeholder’s perspective that are stopping the intended occupants of the building becoming more sustainable, so that this can be considered in the development of the sustainability framework for the building. It was intended that this understanding can then be integrated into a project specific sustainability framework, which adds value to the building and its occupants when they move in thus integrating knowledge from an extended peer community of non-experts.

8.2.2 Action Research Case study 1C: new college and exhibition space

The project is located in Cornwall in the UK and had a diverse range or requirements. It had educational requirements, but also had to provide a conferencing facility, and there was also a desire to have a large multi-use space. Due to the funding mechanism for the project the design team had to progress the design, unsure of whether the project had got planning permission or whether funding would be granted from the funding body. Funding requirements meant that the design had to progress at a certain speed to meet funding deadlines as imposed by the funding body. It builds upon the work of the previous case study and was conducted between May and August 2012.

8.3 Action research process

The following action research process was undertaken on Case study 1B.

- Diagnosing
    - Literature review to identify gaps in the literature and potential techniques (see Section 2 and 3.

  - Development of techniques to be suitable for the construction industry context with industry practitioners
- Planning
  - Identification of potential clients to trial approach on
  - Stakeholders identified by project manager
  - Development of workshop facilitation packs and introduction to approaches to facilitators from the sponsoring organisation
  - Development of feedback form to assess the success as capturing the stakeholder's sustainability perspectives
- Taking Action
  - Workshop held with stakeholders, with observation and output captured
  - Results from survey analysed and circulated to stakeholders in an pre-workshop information pack
- Evaluating
  - Workshop output analysed
  - Results written up and circulated to attendees and design team
  - Feedback analysed
  - Approaches presented to numerous groups in the sponsoring organisation with opportunity to feedback.

However, it should be noted that this also provided learning that was then used on Case Study 1C. Case study 1C followed a similar action research approach to that above, but was then complemented with additional workshops and iterations of the action research process. Additionally, this included learning from the feedback from the workshop, that prior priming of the workshop participants with respect to what will happen on the day would have been beneficial. Therefore, three workshops were held, the first to engage the participants and give them an introduction to some systems thinking principles and what would happen in the second (understand) workshop, which used the more successful techniques from the workshop undertaken on Case study 1B. Then the report was circulated outlining the results, before the results were presented back to the project team in the final "Define" workshop, with opportunities to ask questions and feedback.

8.4 Methods

This section describes the rational for the choice of methods for eliciting the stakeholders' views on what was important with respect to sustainability considerations of the project. This was focused around a 5 hour (11am-4pm) workshop held at the university building. The approach aimed to gain stakeholder's opinions on sustainability and using their understanding to inform the development of a project specific sustainability framework. On the day, a variety of techniques were used in several sessions conducted over the course of the day. These were informed by academic techniques arising from the field of management and applied in the context of building design.

The research acknowledges that the researcher is taking an inductive approach as he is fully submersed in the research process. The inductive approach is built on the pragmatic realist stance that research is aiming to collect both qualitative and quantitative context specific data to inform the sustainability framework for a building project. It is aiming to understand the effectiveness of different approaches in eliciting stakeholder opinion judging the approach against criteria defined as important for sustainability assessment as outlined in the literature review. Limitations of such approaches are their ability to generalise the results of the findings however, every design project is different including often unique contexts and stakeholder groups. Thus generalising across projects is difficult and is not the aim of the study.

The workshop for Case Study 1B took place on the 4th May 2012 between 11am and 4pm. The workshop was attended by 29 people from 17 different stakeholder organisations. This included 5 facilitators, which included the researcher. A further 4 attendees were members of the design team and included the architect, change management consultant and two project/cost managers. The results for Case Study 1B will be primarily covered in this section, as the techniques used across both case studies were similar. However, learning points that were integrated into Case Study 1C will be discussed in the *"Discussion"* part of this section of work.

Facilitators were talked through the process and intended outcomes prior to the workshop and each received a facilitation pack before the event, which included prompts and questions if the conversation was drying up. The approaches and techniques in the facilitation pack were developed and written by the researcher based on the work of others. The facilitation pack is included in Appendix G.

Attendees were also given an information pack at the start of the day, which included a project summary, the purpose and objectives of the workshop, a list of attendees, a workshop agenda and a feedback questionnaire.

For each session the larger group was split into four groups each with a facilitator. A presentation and short introduction was given via a PowerPoint presentation prior to the start of each session and the attendees were asked to ask questions if the structure, tasks and intended outcomes of each session was unclear. The structure of each session along with the purpose is outlined briefly below.

Groups were allocated before the workshop in an attempt to ensure diversity in each group, and that sustainability was considered from several different perspectives in each case. Smaller groups were formed to encourage open debate and allow greater participation of the group members as well as establish relationships on the day. At the end of the session there was an opportunity for a person from each group to feedback to the wider group a brief summary of their thoughts and opinions.

Names of the people representing each group were recorded on the day so that the output of each session could be traced back to those involved in the group. After each session the output of the session was captured via photographs and left with the groups for reference as and when required in later sessions. Facilitators also took notes during the sessions where possible.

The purpose and structure of each workshop session is briefly explained under the following headers.

8.4.1 A sustainable work place is…

This session had the purpose of understanding what represented a sustainable place of work for the workshop stakeholders. The session involved splitting the stakeholders into four groups each containing 5/6 people and a facilitator. The 35-40 minute session included introduction to the purpose of the session and a quick overview of the structure and allocated time by the researcher. The first part of this session participants were encouraged to spend 5 minutes to first introduce themselves and give a little description of the organisation that they were representing. After this each group was asked to undertake 5 to 10 minutes of silent ‘brainstorming’ and to capture as many thoughts as possible on what represented a sustainable place of work. In order to give their phrases structure they were asked to complete the sentence, “A sustainable place of work is...”.

Silent brainstorming, also known as brain-writing, or free-listing was chosen for the initial period. Brain-writing is a method for rapidly generating ideas, by asking participants to write them down on paper rather than shout them out (Wilson, 2006). It was selected as the first method of eliciting stakeholder opinions as it offered a method that helped prevent some of the factors that reduce productivity in brainstorming groups which include: production blocking, evaluation apprehension and free riding (Diehl and Stroebe, 1987). Additionally brain-writing has been shown in some instances to increase the generation of ideas by up to 40% (Paulus and Brown, 2003). As the facilitators for the session, which included the researcher, were not trained facilitators, it also provided a method of militating against group think. The ideas captured on post-it notes were then placed on flip-chart boards. The method was self-organising with participants placing their post-it notes near similar post-it notes of others. This form of pile storing offers the advantage of structuring post-it notes around the stakeholders' sense making, which is considered pivotal to consensus (Maitlis, 2005).

After this initial brain-writing session the facilitators aimed to understand whether the initial output was comprehensive. Dialogue proceeded between the stakeholders, with additional ideas being captured by the facilitator as and when considered appropriate by the stakeholders.

Additionally, where people had similar ideas that were repeated several times, it was discussed whether this reflected the importance of the ideas or merely was because they were obvious considerations. Discussion around the ideas also allowed grouping of similar ideas into themes. It was intended that this would provide a start to developing a shared understanding around which sustainability could be discussed for the group. Thus the approach would provide opportunities for collaborative learning and transfer of knowledge and integrate stakeholder values into the design and delivery of the built environment. Further benefits would be the integration of stakeholder knowledge rather than just the consideration of purely expert knowledge. Thus the session was aiming to address many areas which have been identified with respect to improving assessment methods.

Additionally, the facilitators had prompts within their facilitation packs which asked groups to consider the life cycle and also the scale at which they were thinking. For example, if they were considering purely building services systems, to think about the impact of the building on the site.

8.4.2 Project constraints and opportunities

This 40-45 minute session was designed to understand the constraints and opportunities that different stakeholder groups have in trying to improve the sustainability of the place in which they work, so that this understanding could be incorporated into the development of the sustainability framework. It was considered that trying to think about the issues from two different perspectives would provoke thought and allow creative ways of addressing issues. The workshop participants were also asked to share their ideas on how the constraints or opportunities they identified could be respectively reduced or exploited. This session was structured based upon a Lewin's Force Field Analysis (Lewin, 1952) (see Figure 8—1).

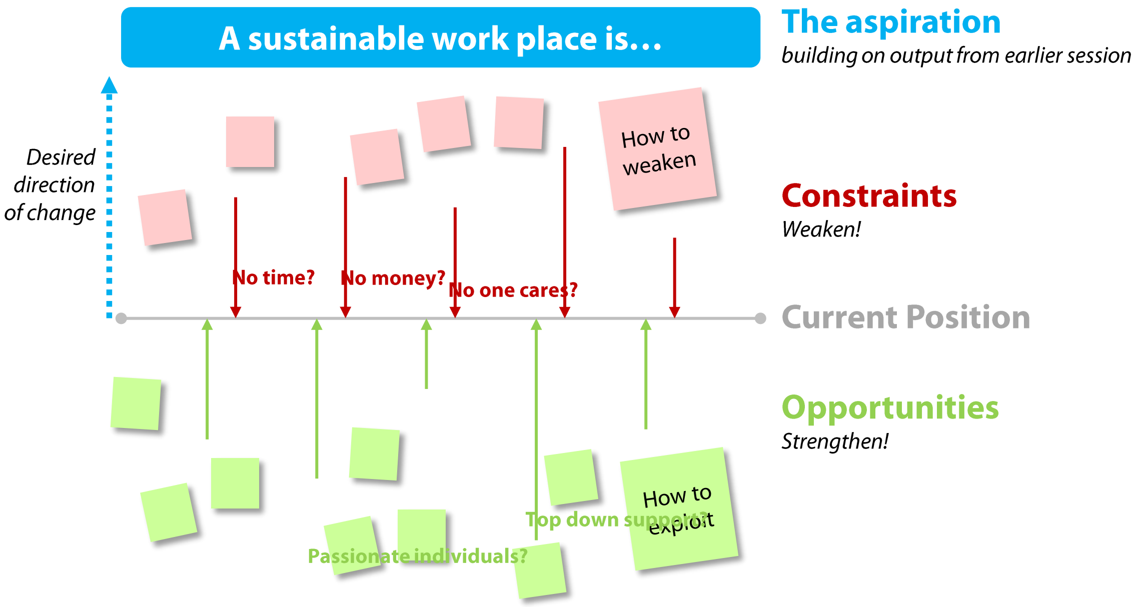


Figure 8—1 Project constrains and opportunities - Intended structure of output

This provides a framework for looking at forces (factors) that influence a situation. The approach was originally used in social situations, but has been adapted for use in organisational development, process management and change management. It has recently been used in the context of analysing the potential of the use of building integrated photovoltaics in the Gulf region (Taleb and Pitts, 2009). Since the desired outcome is a change to a more sustainable work place in this case, this author considers that it is reasonable to use it in this environment. Additionally, it provides a model to think about the problem from both a drivers (opportunities) and barriers (constraints) perspective. Similarities between Lewin's Force field Analysis and Senge's Systems Architypes are outlined in Buchanan et al. (2005). One particular aspect is worth considering and is highlighted by Senge et al. (1999) who state the following:

> *"Sustaining any profound change process requires a fundamental shift in thinking. We need to understand the nature of growth processes and how to catalyse them. But we also need to understand the forces and challenges that impede progress, and to develop workable strategies for dealing with these challenges. We need to appreciate 'the dance of change', the inevitable interplay between growth processes and limiting processes."*

This supports the use of the technique here. Design is ultimately a change process aiming to provide something new that has a positive impact. Senge (1990) refers to such change problems conforming to a 'limits to growth' archetype, which is represented by a reinforcing process and a balancing process. Senge explains, with such archetypes an effective management principle for continued growth (or change in reference to Lewin's model) is in removing the factors limiting the growth. This is in opposition to strengthening factors of the growth, which is often where people focus their efforts. Therefore, structuring the workshops participants input in such a way may help identify high leverage ways to progress.

Additionally, the approach outlined above, has certain similarities to approaches such as Interactive Planning as detailed by Ackoff (2001) and Checkland's soft systems methodology. For example, with respect to interactive planning, there are similarities between ends planning and means planning and trying to close the gap between the current and the desirable state. With respect to soft systems methodology, steps 6 and 7, which are concerned with *"Defining changes that are desirable and feasible"* and *"Taking action to improve the real world situation"*.

To tie this workshop technique back into the first session of "A Sustainable Building is…", workshop participants were asked to consider their output from the previous session as the goal in which they were trying to move towards.

8.4.3 Introduction to the project

A ten minute introduction was given to the project. This was to give an understanding to those who didn't know the building to understand some of the project constrains and the potential opportunities. It was intended that this understanding could then be used to discuss sustainability specifically for the project context during the breakout sessions in the afternoon.

8.4.4 Importance vs influence of design team

This 25 minute workshop session was structured to consider which aspects were most important from a sustainability perspective and also consider which of those aspects the design team could influence. It was also intended that the session could be used to start to develop a common understanding of what might be possible through the design, but also consider which issues would have to be addressed by the project's stakeholders through the design life of the building. Stakeholders were asked to organise their thoughts as shown in Figure 8—2. This was an adaption of the widely used Influence vs Interest grid that is typically used to categorise stakeholders. However, as the purpose of this session was to consider what the design team could influence, it was considered that the sustainability themes that had been emerging through the earlier sessions should be plotted against their importance from the perspective of the participants, and with respect to how much the participants thought the design team could influence particular aspects. It was intended that issues categorised as high on both axis should be focus areas for the design team to address. Additionally, the design team would be able to respond if they felt that they didn't have much influence over a particular issue. Essentially the purpose of the session was to also manage expectations on behalf of the design team and get the stakeholders considering who could influence the achievement of a theme if the design team didn't have all the influence.

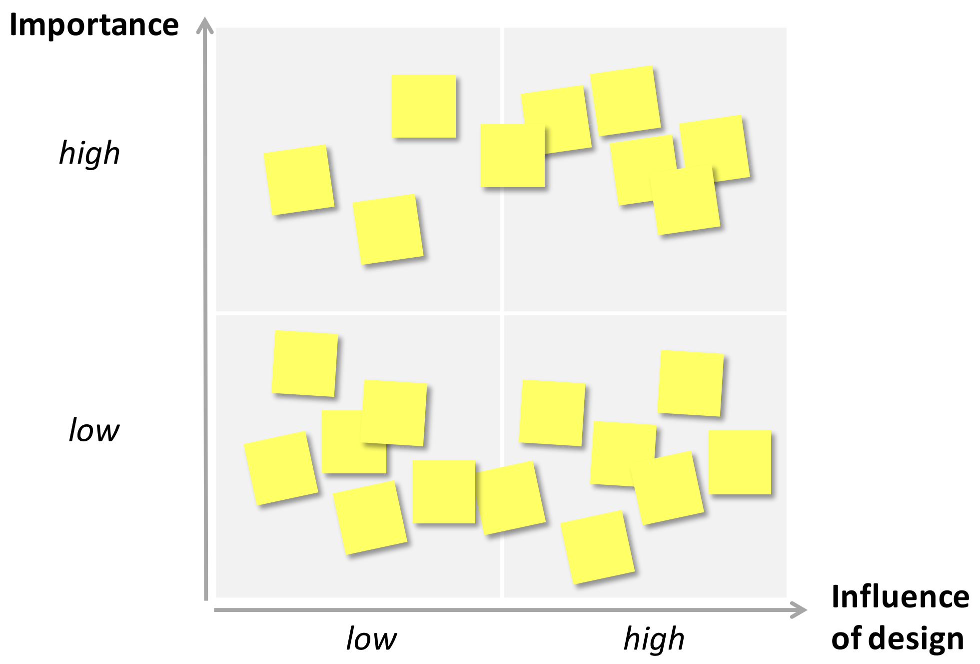


Figure 8—2 Importance vs influence of design team for sustainability issues

8.4.5 Prioritisation of key themes

This 25 minute section focused on prioritising key items and themes identified as important during the previous exercise. Understanding stakeholder priorities is important for the design team to inform their decision making and where to focus design efforts. Otherwise they have to assume the priorities of the stakeholders/client. Additionally, it was considered important for the stakeholders to think about these issues and clarify which aspects were more important. The expected outcome of this exercise was a prioritised list of important sustainability themes and items to consider during the design. It was also to check consistency across sessions, as the output should closely align with that of the previous exercise. The output was expected to be a ranked list, with the most important themes towards the top of the list.

8.4.6 Relationship mapping

The focus of this 25 minute exercise was to map interventions and consider how these impacted on sustainability considerations they had identified as being important. The intention being to identify potential conflicts and win-win scenarios. This is based on group model building (Vennix, 1999) as described in Section 4.3.2.4. Sustainability is complex and therefore the relationships and interdependencies need to be considered. This exercise was aimed at developing the groups' understanding collectively on the interrelationships for the building on these issues. The intended outputs of the exercise were relationship maps produced by the groups that resemble the map below. This built on earlier work undertaken on Case Study 1A and it was the example developed for the Pre-prep School which was used to explain the structure and the intended outcome. This was done prior to the workshop. The intention was to facilitate a session in which this was done in collaboration with workshop participants using the structure as shown in the previous example.

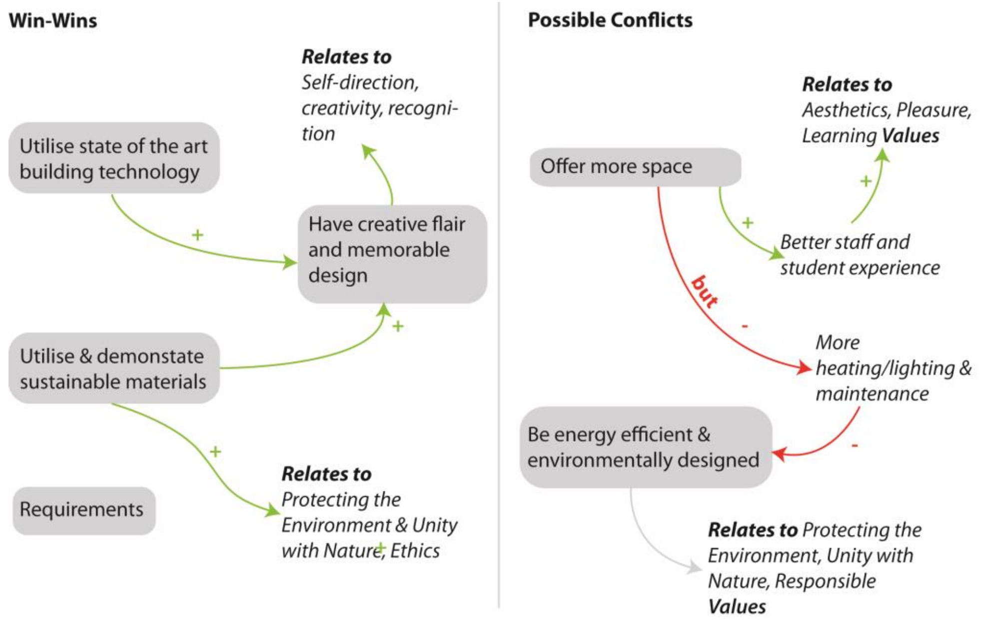


Figure 8—3 Example of structure to the session

8.4.7 Stages of the sustainability process: management and reporting

The purpose of this session was to gain the stakeholder input on important issues regarding the development of the sustainability framework. These included emphasising that the sustainability framework should not just be a design tool, but to be effective should run through the construction, handover and operation of the building. With respect to this the stakeholders were asked to feedback on the following aspects:

- Who should own / manage / be responsible for the framework at different stages of the project?
- How did you foresee the framework being implemented?
- What are the external requirements of the framework?
- How should this be related to standard environmental assessment methods e.g. BREEAM?
- How you foresee a bespoke approach offering a robust and valid process?
- What do you consider to be the benefits of a bespoke sustainability framework?

Essentially this was structured to try and facilitate stakeholders to consider the life cycle of the building beyond just the design and how this should be structured and owned. Thus addressing issues with respect to 'lack of integration and communication' and consideration of the life cycle.

8.5 Results

The results presented below are taken from the report circulated to stakeholders. It shows the analyses of the output of the stakeholder engagement workshop which was held on the 4th May 2012 with respect to the sustainability for the project. It first shows the output, then analyses the agreement and disagreement across the groups on issues considered to be important with respect to sustainability. In the interests of openness and transparency, the method of analysis was also explained in the report. Additionally, images of the raw output of the workshops are typically included and the results of the analysis are shown. The report was reviewed by another sustainability consultant who was also a facilitator at the workshop to check that it reflected their understanding of the output of the day. The report was circulated to all stakeholders and they were encouraged to feedback if the report was not considered representative from their perspective. No comments were received.

8.5.1 A sustainable place of work is…

The output of the session included a series of flip chart sheets from each group containing their ideas on what sustainability meant to them individually and collectively as a group. The facilitators aimed to also categorise ideas that arose from the silent brainstorming session as well as capture thoughts from the dialogue that were missed during the silent brainstorm. Figure 8—4 and Figure 8—5 relate to two of the groups and are shown below. This formed the starting point for the analysis after the workshop.

Figure 8—4 Group 1 – a sustainable place of work is...

Figure 8—5 Group 3 – a sustainable place of work is...

output	**output**

Each post-it note was transcribed after the workshop and put in a database (Table 8—1). This provided a large qualitative dataset regarding the stakeholder opinions on what a sustainable place of work represented to them.

The transcription simply included the comment as originally stated. Data was also captured in which workshop group the comment was made as it was thought that this would provide an audit trail and increase the transparency of the approach. This is useful for being able to trace back comments to the individual in those groups and understand which organisations this was representative of. Once the comments had been transcribed an automatic word count analysis was applied to the themes using www.wordle.net. This simply lists the number of occurrences of different words and sizes words according to the number of times they were present in the comments to produce a word cloud. Common English words are filtered out of such analysis.

Figure 8—6 shows the simplified process of how the workshop post-it notes were analysed.

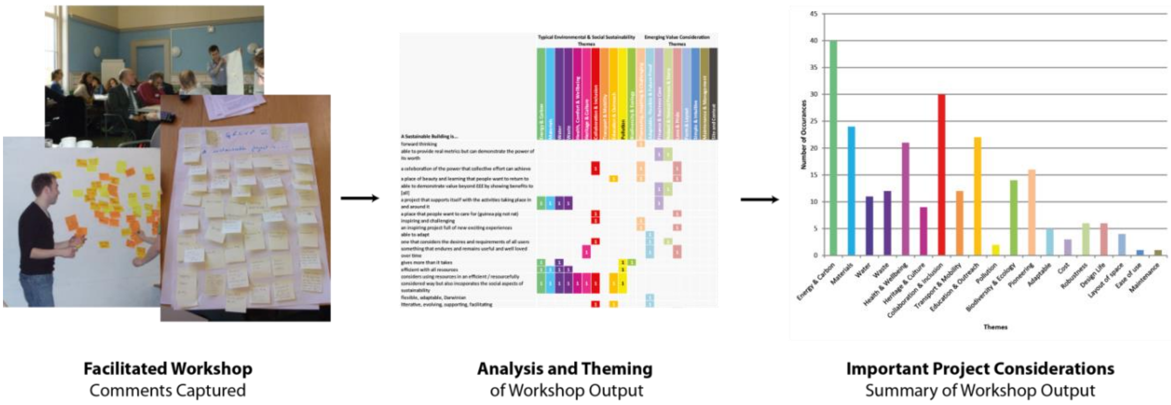


Figure 8—6 Analysis approach

Saunders et al. (2003) state that analysis of qualitative data can be done in the following broad ways:

- Summarising (condensing) of meanings
- Categorisation (grouping) of meanings
- Structuring (ordering) of meanings using narrative

Comments were also post analysed after the workshop and were categorised accordingly. This is considered a formalised method of data analysis. Categorisation is considered to involve two activities, developing categories and subsequently attaching categories to meaningful chunks of data (unitisation).

Categories were originally developed in a combination of three ways:

- From the sponsoring organisation's typical sustainability themes, such as energy and carbon, materials, water etc. This could be classified as a somewhat deductive approach
- However, where it was considered a post-it note did not fit into a typical sustainability theme, a new category was started. Additionally, themes were also identified through considering the key words emerging from the word count explained above.
- Finally during the workshop session, participants were also asked to group post-it notes that they considered to be of similar themes. These themes also informed the categories of the analysis.

Therefore, a combined deductive and inductive approach was used to categorise the data.

As participants were encouraged to complete the sentence, *"a sustainable place of work is…"* and for each sentence to be on an individual post-it note the unitisation process was reasonably straight forward.

The main themes that emerged from the exercise were then presented back to the stakeholders in a report format with a narrative and explanation.

Table 8—1 Excerpt from the bottom of the database of post-it note comments.

Group	A sustainable Place of work is...	Energy & Carbon	Materials	Water	Waste	Health & Wellbeing	Heritage & Culture	Collaboration & Inclusion	Transporta & Mobility	Education & Outreach	Pollution	Biodiversity & Ecology	Pioneering	Adaptable	Cost	Robustness	Design Life	Layout of space	Ease if use	Maintenance
3	Integration with wider facilities... Available and easy to use							1												
3	Continuity - users - training and ongoing impacts							1												
4	Renweable Energy (Low Carbon... As much as possible)	1																		
4	Energy Efficient	1																		
4	Low Water impact			1																
4	Abundant access to natural light	1				1														
4	Default low but comfortable heating levels							1		1										
4	Low/negative impact on local community							1		1										
4	Encouraging reducing flying (i.e. Video conferencing and carbon offset)	1							1											
4	Low carbon energy efficiency (new technologies)	1																		
4	A place that can adapt to a changing environment													1						
4	Low impact on the environment	1	1	1							1	1								
4	Have minimal impact	1	1	1	1						1	1								
4	Use of recycled goods/materials for building		1		1															
4	Energy Efficient building, fittings and equipment	1																		
4	Access to sustainable transport								1											
4	Easy Access to wildlife											1								
4	Natural lighting	1				1														
4	Organic fair trade and vegetarian		1																	
4	Access to nature, trees, ponds, wildlife					1						1								
4	Compost		1																	
4	Green roof											1								
4	Overall inspirational and ambitious targets and strategy												1							
4	Easy out reach from building (inside community to community surroundings)						1			1										
4	Recycling and or reusing		1		1															
4	minimum 75% eco sourced timber		1																	
4	Leader in field / exemplar												1							
4	Happy and bright place					1														
4	A workplace that motivates each worker as soon as they enter the building					1		1												
4	Save on running costs	1													1					
4	User awareness of why and how to use building correctly									1										
4	Easy access to green "natural view" and sky					1						1								
4	Accessible by bike/on foot for all workers								1											
4	building specific bikes for visitors etc to use								1											
4	Researched options (dont just assume) e.g. Are wind turbines good?															1				
4	Promotes sustainable living by doing and educating others						1	1		1										
4	Incorporates historic architecture with modern						1													
4	Collaborative and community engagement							1		1										
4	Low growth mentality							1		1										
4	Quiet for working but not cut off					1		1												
4	Enduring adaptation - no need to re-do for ages																1			
4	Surfaces and other elements from recycled yoghurt pots?		1																	
4	Efficient Heating/cooling (natural where possible)	1				1														
4	Engages others in community (Education, design interest?)							1												
4	Interaction with cambridges's sustainability as a whole						1	1		1										
4	Sympathetic (To cultural / historical associations) adpatation						1													
4	Plenty of space for personal files / docs at arms length																	1		
4	Resposible sourcing of consumables		1																	
4	Comfortable					1														
4	Room for improvement & ability to adapt and change to better technology													1						
4	Like / open-minded colleagues with conservation as a guiding principle							1		1										
4	Public visibility of tenants work & visions									1										
		40	24	11	12	21	9	30	12	22	2	14	16	5	3	6	6	4	1	1

From this the number of occurrences or times a particular aspect was mentioned as being representative of a sustainable building can be counted and presented as shown in Figure 8—7.

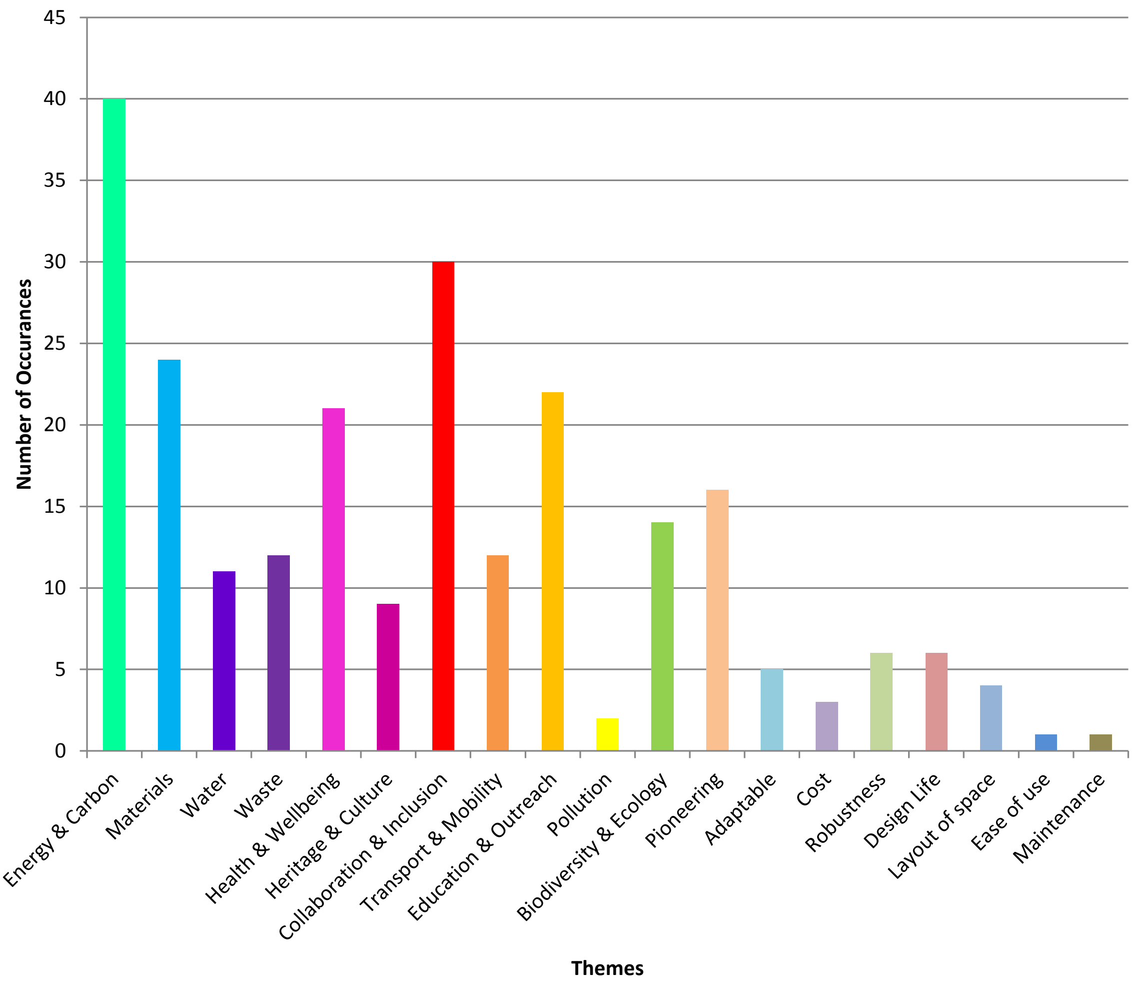


Figure 8—7 Sustainability considerations[6]

The most repeated post-it note comments were in relation to *"energy & carbon"* (40), closely followed by *"collaboration & inclusion"* (30). Whilst *"energy & carbon"* related matters are measured and quantified by most environmental assessment frameworks such as Building Research Establishment Environmental Assessment Method (BREEAM), *"collaboration & inclusion"* is not considered. Whilst this may be more challenging to measure as it is harder to quantify through the design, its high scoring nature highlights that this is something that is important and should be considered. *"Education & outreach"* also scores high (22 references), again highlighting this as an important consideration with respect to the development of a sustainable work place. Again this is not a typically measured element of most buildings, but is clearly important from the perspective of the stakeholder.

[6] Numbers represent the number of post-it notes related to common themes

It was interesting to see that a significant number of comments were related to the need for a sustainable building to be pioneering, with comments such as a sustainable place of work is... *“[a] leader in its field”* and *“innovative and exemplary.”* This should be explored in more depth, and aspects which could be pioneering and delivered within the budget of the building refurbishment should be identified.

Other comments were also identified and grouped under the theme, *“robustness”*. Comments which were classified into this are generally related to the process of the design and continuing on from this the sourcing of materials and construction of the project. Such comments that fall under this theme include, *“life cycle analysis”* and *“continued engagement and evaluation of building use.”*

“Adaptability” and *“layout of space”*, are two other interrelated themes that cropped up a number of times in this first session and should be considered through the development of the architecture and engineering of the new building. Whilst aspects such as *‘maintenance’* and *‘ease of use’* only cropped up once, they are considered to be integral to the sustainability of the building and therefore, were included as separate themes.

Whilst it is understood that the categorisation of comments is a somewhat subjective and inexact procedure, the raw comments as written on the post-it notes for consideration, along with the themes which the analysis team categorised, were included in the Appendix of the report circulated to stakeholders in the interests of transparency.

8.5.2 Opportunities vs. constraints

The structure of the session was intended to encourage stakeholders to think about the problems and issues from both a positive and a negative perspective. However, one person’s constraint could be seen as another’s opportunity and this was reflected in the output of the exercise. Therefore the output of the exercise, rather than forming a ‘strict’ force field model often constituted a list of considerations, sometimes (but not always) with a positive or negative perspective (see Figure 8—8 and Figure 8—9). These were then typically complemented with ideas on how to reduce the constraint or exploit the opportunity as suggested in the workshop structure.

Figure 8—8: Group1 – project constrains and opportunities

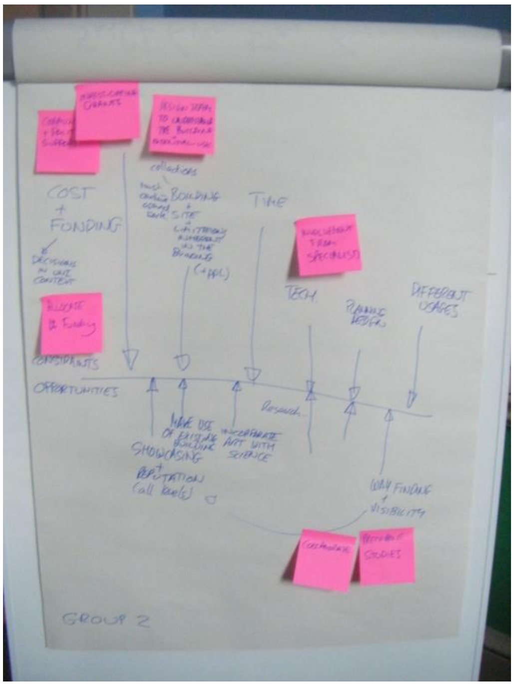


Figure 8—9: Group2 – project constrains and opportunities

Again all the comments from the workshop were transcribed and categorised according to the group from which the post-it notes were defined. The categorisation process, was similar to that as described in the previous workshop session in Section 8.5.1. However, categorisation, in this instance utilised the themes that had been developed from the first session and built on these. Additionally, there was some summarising (condensing) of meaning of the post-it notes.

The analysis first considered each group individually, and then summarised and collated the output for the group as a whole. The analysis involved categorising similar opportunities/constraints into themes, additionally where possible, opportunities were directly related to a constraint and placed opposite each other. Where similar opportunities were identified by different people/groups this was captured by placing a number next to that consideration, which represents the number of times this consideration was mentioned in the output of the workshop.

The analysis and grouping of different items was done based on the thoughts of the researcher and therefore the process cannot be seen as without bias, it was intended that the process was transparent and the photos and individual group analysis before summaries were available to stakeholders if they wished to see how different comments had been categorised. Additionally, to show the strength or occurrence of individual notes numbers representing how many post-it notes considered that aspect are also included. Captured next to the themed responses are the ideas to exploit opportunities or to reduce constraints. An example of the output of the analysis is included in the Figure 8—10.

Ideas on Exploiting		Opportunities		Constraints		Ideas to Reduce
ECRP... Could this be accessed? Donors sympathetic Feed in Tariffs / External Funding	3	Funding	Costs, Money, Time & Funding	Costs/Money	7	Allocating a set amount of budget Investigating grants Engage with community and gain political support ######## retro-fit & University other financial grants/models Collaboration Compare to current energy use/costs
Energy efficiency / onsite generation		Lower running costs with technology		Running Costs		FiTs / Funding
		Business opportunity		Inertia		
				Time		
Link to ########### essential		Central location	Stakeholders / Collaboration	Large number of stakeholders		Community funders visitors, etc. Communication
		Time & Access to people, ease of combs, accidental meetings		Multi-tenants		Communities
				Academics?		
				Mindsets / Old school minds	2	
	2	Change Social Norms		need similar user groups and activities (not like with like)		
		Change in workplace perception				
		Community interaction / education		Apathy		Generate enthusiasm Engagement Competition between groups Conservation - should be convincible Smart metering visible
Communal cafes etc.	2	Social/collaboration		Harnessing University Expertise		Involve Engineering department and sustainable expertise Engage Prof ########### (FRS) Passivehaus expertise
		Communicate achievements				
		Incentivise the good		Behaviour - lazy/disgusting		
		Original designer				
Supply chain visibility			Technology	Untested tech / operation		Test bed for innovation
				Internal environment (hot/cold)		Evolve internal environment
Adaptability to future tech Undertake research into best examples	2	Technology		Technology (Rapid Changes)	2	Team/sharing
		Technology		Technology		
				ICT		
				Renewable energy		

Figure 8—10 Excerpts from opportunities and constraints analysis

Through providing a different structure to the session, issues emerged which were not considered in the same amount of depth in the first session. These included a stronger and much more explicit consideration of costs by the workshop participants. Additionally, stakeholders and collaboration were thought of from different perspectives, which also highlighted potential issues at an early stage. This allows the client, project management and design team, to plan how to consider such issues as the project progresses.

Pros and Cons of the following key themes were discussed during this section

- Costs, Money, Time and funding
- Stakeholders / Collaboration
- Existing / Future Building
- Technology
- Transport

It should be noted that there was also significant input with respect to how to address these themes which was considered important with respect to integrating stakeholder's knowledge of the problem context. These included thoughts on budgeting, raising more money, engaging with the wider community to gain political support, investigating grants, and tapping into other external funding sources.

8.5.3 Importance vs. influence of design team

The output achieved from the session was typically of high quality, with lots of engagement and ideas captured on the boards. However, there were some issues with respect to being able to select the most important issues, and also which issues were more influenced by the design. This meant that the output was often focused around the top right quadrant (issues which were classed of high importance and highly influenced by the design). Examples of the output achieved from the session are included in Figure 8—11 and Figure 8—12.

The analysis in this section involved transcribing the output of the session, and giving the output items a score for both importance and influence on a scale from 0 to 10. This was done after the workshop by the analysis team in relation to where the post-it notes had been placed on the flip chart grids. Whilst some items had been placed off the grid to emphasise their importance, these were given the highest importance/influence by the analysis team, and then the rest were distributed accordingly. Additionally, each item was categorised according to the theme that was assumed to be the most relevant for each item respectively. Post-it notes were categorised according to the themes identified in earlier workshops session. This was to allow the design team to see if some themes were emerging as more important and further develop the understanding from the output of the first session. Each group was analysed individually and then the results were collated to show the results of all the groups as a whole. This can be seen in Figure 8—13. Figure 8—13 is split into quadrants, representing high/low importance vs. high/low influence of design. The below commentary will discuss aspects which occur multiple times in relation to their importance and the influence of the design.

From the analysis the most common theme rated as 10/10 on the importance scale three times, was *‘robustness’*. These comments included; *‘demonstrably efficient (to staff and visitors)...’*, *‘transparency and monitoring’*, and *‘information visibility and engagement’*. Comments categorised into the theme *‘robustness’*, came from groups 1 and 3. The theme ‘health and wellbeing’ was also classed as important consideration, occurring twice in the highest importance (10/10) and four times in the top right quadrant representing high importance and high influence of design.

Figure 8—11 Group 1 – what should sustainability mean for this project output

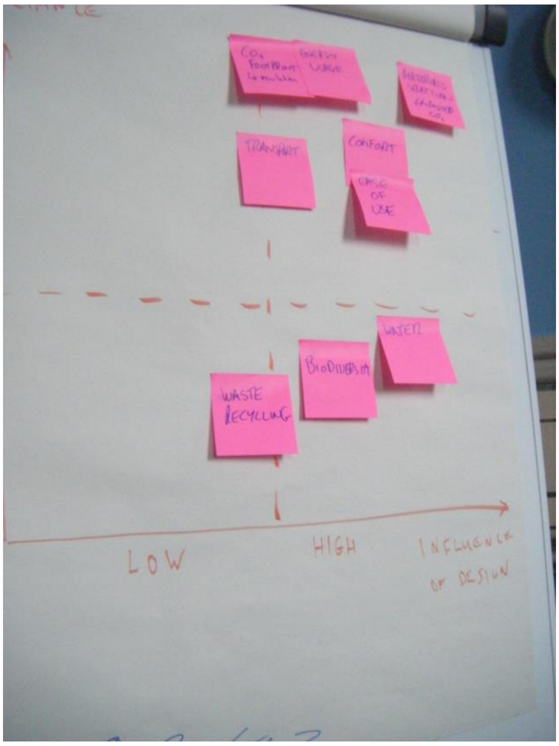


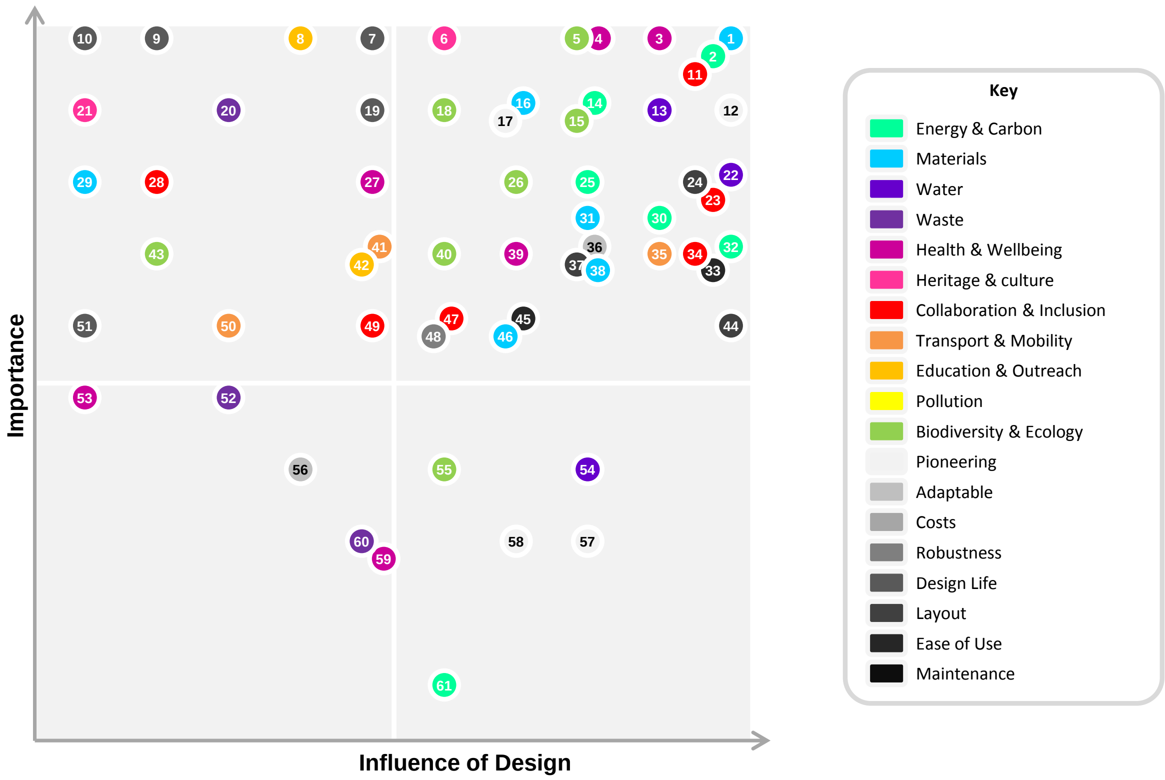
Figure 8—12 Group 2 – what should sustainability mean for this project output

Comments relating to the theme, *"energy and carbon"* also were repeated several times in the high importance and influence quadrants. However, one 'energy and carbon' issue written in relation to a specific target, 'carbon neutral', was categorised of low importance.

The joint most popular themes in the high importance and influence quadrant were *'materials'*, *'biodiversity and ecology'*, and *'collaboration and inclusion'*. Each had five references. It was generally recognised that whilst design had a strong influence on *'biodiversity and ecology'*, the influence of design was not the only factor. This was also true of *'collaboration and inclusion'*. The influence of design on *materials* related comments was also seen to be very high.

It is interesting to note that with respect to *'collaboration and inclusion'*, some related issues such as 'shared facilities' can be influenced strongly by the design. For such facilities to be used in a collaborative and inclusive manner will also require a certain culture. Whilst this can be encouraged by the design, culture is emergent from a wide range of interrelated issues that are external to the design, and therefore stakeholder expectations should be managed accordingly.

Biodiversity and ecology, was generally considered to be important and highly influenced by design. In discussions in group 2, it was considered that the biodiversity should be considered more in reference to what goes on in the building (i.e. the purpose of the lead organisation), rather than necessarily incorporating bio-diverse features in the design. However, this was not necessarily a shared view across the groups. This was highlighted as an areas to be explored in more depth as information becomes available from the design team on the cost/implications of integrating ecology and biodiversity in to the design.



Ref.	Gr'p	Consideration	Importance	Influence
1	2	Materials selection (Embodied Energy)	10	10
2	3	Energy efficient	10	10
3	4	Internal environment - accoustics, lighting, ventilation	10	9
4	1	Exemplar wellbeing	10	8
5	4	Impact on biodiversity	10	8
6	3	Building makes right behaviour easy	10	6
7	3	Demonstrably efficient (to staff & visitors) - energy, water	10	5
8	3	Communicable to the public	10	4
9	3	Transparency and monitoring	10	2
10	1	Information visibility & engagement	10	1
11	1	Collaborative environment for work	9.5	9.5
12	1	Beacon	9	10
13	3	Sustainable water	9	9
14	1	Low Carbon / energy / in use	9	8
15	4	Biodiversity - access to	9	8
16	1	Materials - building, In Use	9	7
17	4	Cloud computing for services	9	7
18	1	Connected to external environment	9	6
19	1	Sustainability auditing	9	5
20	1	Waste	9	3
21	1	User beahviour & culture	9	1
22	1	Water management	8	10
23	4	Shared facilities (meeting rooms, common areas, end user collaboration)	8	10
24	4	Fabric upgrade	8	10
25	4	Rnewable energy	8	8
26	1	CCI / Conservation group ethos	8	7
27	4	Enable staff productivity	8	5
28	4	End user collaboration	8	2
29	4	Purchasing strategy - goods	8	1
30	4	Energy efficiency - technical, fabric	7.5	9
31	4	Materials life cycle use	7.5	8

Ref.	Gr'p	Consideration	Importance	Influence
32	2	Energy usage (CO2 footprint)	7	10
33	3	Flexible (considers users / space)	7	10
34	4	Video / teleconferenes	7	10
35	4	Transport strategy	7	9
36	1	Adaptability	7	8
37	3	Design Life (longevity & lifecycle)	7	8
38	4	Materials of construction	7	8
39	2	Comfort	7	7
40	1	Active biodiversity	7	6
41	2	Transport	7	5
42	3	Should consider wider footprint (e.g. Staff travel)	7	5
43	4	Green external area	7	2
44	1	Climate smart (2040 - 2060)	6	10
45	2	Ease of use	6	7
46	3	Choice of Materials	6	7
47	1	Collaboration / engagement / external	6	6
48	3	Meets business needs	6	6
49	1	Community connections	6	5
50	1	Transport / cycling	6	3
51	3	certified as such (ISO?)	6	1
52	3	Able to manage waste effectively (materials/heat)	5	3
53	3	Doesnt reinvent the wheel	5	1
54	2	Water	4	8
55	2	Biodiversity (on building)	4	6
56	4	Flexibility of furniture	4	4
57	3	Use of innovative technologies	3	8
58	3	Unusual opportunity for innovation	3	7
59	1	Environmental comfort (Future Proof)	3	5
60	2	Waste recycling	3	5
61	3	Carbon neutral	1	6

Figure 8—13 All groups importance vs. influence results

Issues relating to the themes water, waste and to some extent materials, were repeated several times. However, with a large spread on the degree of importance/influence. For example, group 3 had the issue 'sustainable water' classed as highly important (9/10). This was also considered as highly important by group 1 (*'water management'*, 8/10). Both groups considered the influence of the design on water use as high (8 and 9/10). Whilst group 2 also considered the influence of design on water use to be high, they considered water use to be only 4 on a scale of importance. This highlights some diversity across the groups on this issue. A similar amount of diversity can be seen across groups on issues relating to waste, with 2 groups scoring waste relatively low in terms of importance (5 and 3 out of 10) whilst another group scoring waste as 9 in terms of importance. However, all three groups were in more agreement as to the extent at which the design could influence this scoring the influence of design as (3, 3 and 5). Materials again saw groups with slightly different opinions; however materials issues were generally focused in the top right quadrant showing that most groups agreed that they were both important and highly influenced by design. The only materials issue that was not in this quadrant was related to purchasing strategy of goods, which whilst still been classed as important was not highly influenced by the design.

8.5.4 Prioritisation of key themes

The output for the groups is shown below. On reflection stakeholders found it difficult to prioritise which aspects of sustainability were more important for the project. This was typically due to items not necessarily being similar (or like with like). For example, some items discussed were in relation to the process of delivery of the building, whilst other items were to do with the output of that process (i.e. features of the completed building). Additionally, not all participants found it appropriate to rank these issues, stating that, *'cross-links and synergies are [more] important'* see bottom of Figure 8—14. For these reasons the output of the exercise was not as consistent as anticipated.

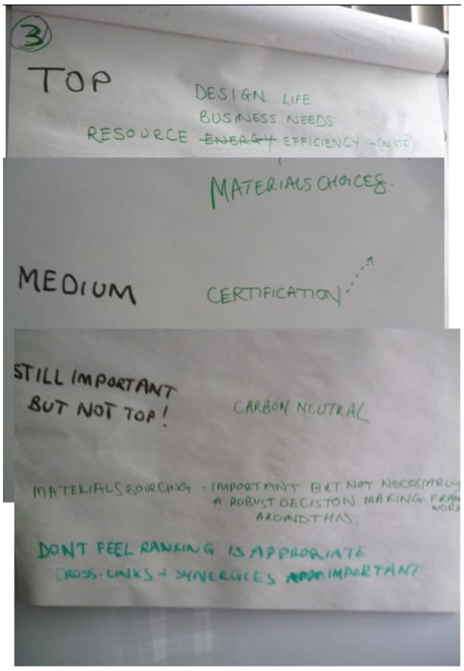


Figure 8—14 Group 3 – output of prioritisation of issues

Figure 8—15: Group 4 – output of prioritisation of issues

The analysis of this section involved capturing the criteria that had been ranked by the various groups, and looking for similarities and differences. The analysis team split the list into items related to process of delivery of the building, and the features of the refurbished building. As there was no way of collating the priorities across groups into one list of priorities the lists have been kept separate and similarities and differences across the lists discussed.

Issues relating to the theme *"energy and carbon"* appear on each group's list of priorities indicating that this is of importance for all groups. Whilst group 3 specified this as their lowest choice, it was under the header of *"still important, but not top".* Additionally, their comment in relation to energy is a lot more specific than the other groups' comments stating a target of *"carbon neutral"*. Issues classed under the theme of *"robustness*" also occur in each list under the heading of *"process*" which signifies the importance of well justified choices with respect to sustainability. Materials issues arise under both consideration of outcome and process, with materials choices and sourcing being a key issue with respect to both the process of delivering the building and outcomes of the construction. Transport strategy, whilst not a key criteria emerging from the previous session arises on three groups' priorities lists. Whilst this is not solely influenced by design, it appears that there is a priority to develop a transport strategy and provide facilities for cyclists. *'Water'* (management), *'biodiversity and ecology'* and *'health and wellbeing'* were also key priorities mentioned on three lists each.

Group 1	
Outcomes	*Process*
Collaboration / External Engagement	Exceed standards where they do exist
Collaborative environment for work	Set standards where none exist
Active biodiversity	Sustainability auditing
Exemplar wellbeing	
Adaptability	
Beacon	
Low carbon energy / renewable	
Climate smart 2040 - 2060	
Water management	
Materials - building, in use	
Waste	
Transport / cycling	

Group 2	
Outcome	*Process*
Working environment	Robust evidence
Energy	Materials sourcing
Waste	
Water	
Transport	
Biodiversity	

Group 3	
Outcome	*Process*
Design life	Materials choices
Business needs	Certification
Resource efficiency - (in use)	Materials sourcing
Carbon neutral	

Group 4	
Outcome	*Process*
Materials of construction (timber, paint, plaster, insulation)	Good management of process of construction. E.g. Waste, social interuptions
Renewable Energy (Sourcing Energy)	
Materials - lifecycle use (purchasing policy once the building is done)	
Energy efficiency	
Internal Environment... Acoustics, lighting, ventilation	
Transport strategy	
Shared facilities	
Cloud computing for services	
Water management	
Improve, local biodiversity e.g. Roof garden	
Video/teleconferencing	

Figure 8—16 Lists of considerations from prioritisation session

The session however, was considered by many participants to be repetitive and this is captured in the feedback to the workshop. Some thought that there was too much emphasis on prioritisation. This perhaps aligns with Keeney's (1992) argument that prioritisation without understanding the relative "swing" in performance on the particular aspects is a difficult exercise. This is explained more in Section 3.7.3 as the relative importance should consider the scoring of the alternatives.

8.5.5 Relationship mapping

The outputs of this session considered the interactions between issues and interventions. Whilst the output is interesting, the purpose of doing the exercise was to collectively think and develop a shared understanding of the inherent trade-offs between sustainability interventions amongst stakeholders. Therefore, the primary purpose was to begin to build a collective understanding of the issues and relationships of selecting sustainable design options. In depth analysis of this exercise was not undertaken, as it was not considered feasible at this stage, as there is not enough information to be able to assess whether the positive/negative relationships mapped were correct for the items considered. It is likely that a more comprehensive analysis will be undertaken at later stages of the development of the sustainability framework when design options are being considered in more depth by the design team.

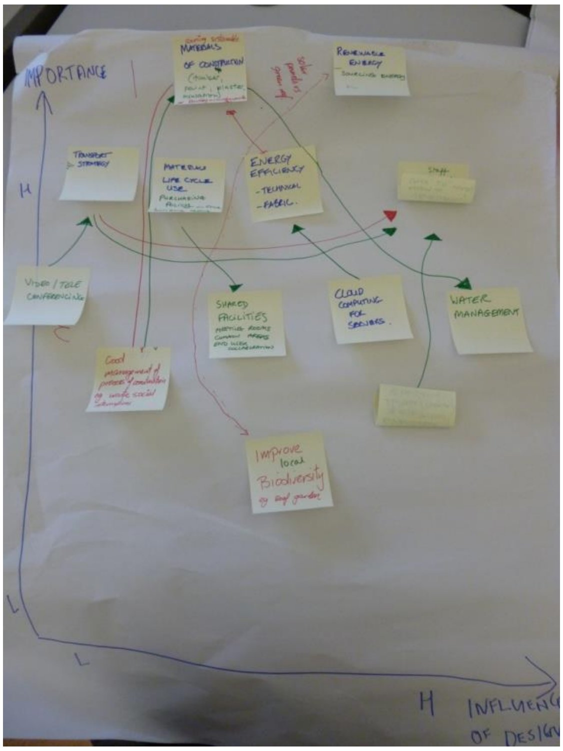


Figure 8—17 Group 4 – potential conflicts and win-wins

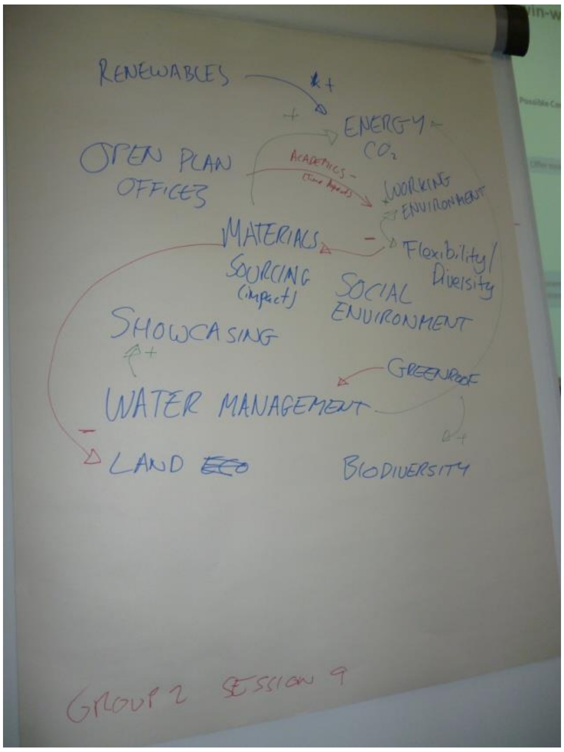


Figure 8—18 Group 2 – potential conflicts and win-wins

Figure 8—19 shows the output of this session after items have been themed by the analysis team. This section discusses the key themes and relationships that emerged from the exercise.

The theme of energy was a key consideration in the groups' thinking during this exercise. However, it should be noted that this may be because relationships between design issues and energy use are generally better understood than relationships between other issues such as collaboration. However, separate mentions of renewable energy generation means that renewable options for the building should be assessed. Renewable energy was seen by the workshop participants to potentially have a negative influence on biodiversity, as they would both be competing for the same roof space. However, it should be considered that it is possible to combine renewable energy with green roofs with mutual benefits for both biodiversity (depending on the target species) and the output of renewable energy.

Green roof as a design intervention occurred twice during this exercise in relation to biodiversity and thus merits further consideration by the design team. Water management also occurred twice and was considered to be negatively impacted by the installation of a green roof by one group. In dialogue with the team, they mapped this relationship negatively as they considered that the green roof would hold rainwater and therefore would reduce runoff that could be collected through a rainwater harvesting system.

Open plan offices were also mentioned twice and were highlighted under the theme 'layout of space' by the analysis team. Interestingly, one group had potential positive implications in terms of the working environment for some users and thought that the academics would not like open plan working with respect to their working environment. Open plan offices were seen to have a positive impact on energy use by one group, highlighting that open plan space would improve ventilation and provide more daylight. This group also considered that less energy may mean less control over their internal environment.

Flexibility occurred on two separate occasions and for the purpose of this exercise was grouped under the theme 'layout of space', which was a well-represented theme. Flexibility was considered as potentially having a negative impact on materials use, as flexible spaces might mean larger structural spans and more redundancy and thus the use of more materials. Materials impact was also seen to have a negative impact on land economy in the same group's thinking.

Comments relating to the themes, *'robustness'* and the need to be *'pioneering'* were considered, however they did not occur with the same degree of frequency as in previous exercises.

Whilst the analysis highlighted some potential relationships that may have been missed by the design team, for example the potential impact of open plan working spaces on academics, more information is required to map whether the relationships are negative or positive with a degree of confidence. Such information will also be able to inform the strength of the relationships with more certainty, which is not possible at this stage. This should be done by the design team as the design progresses in collaboration with the client and stakeholder groups.

However, the output of the session was considered useful by the design team in understanding some of the issues, but also the facilitators of the groups also stated that it provoked discussion and also got people thinking about the inter-connected nature of how potential designs and requirements were inter-related.

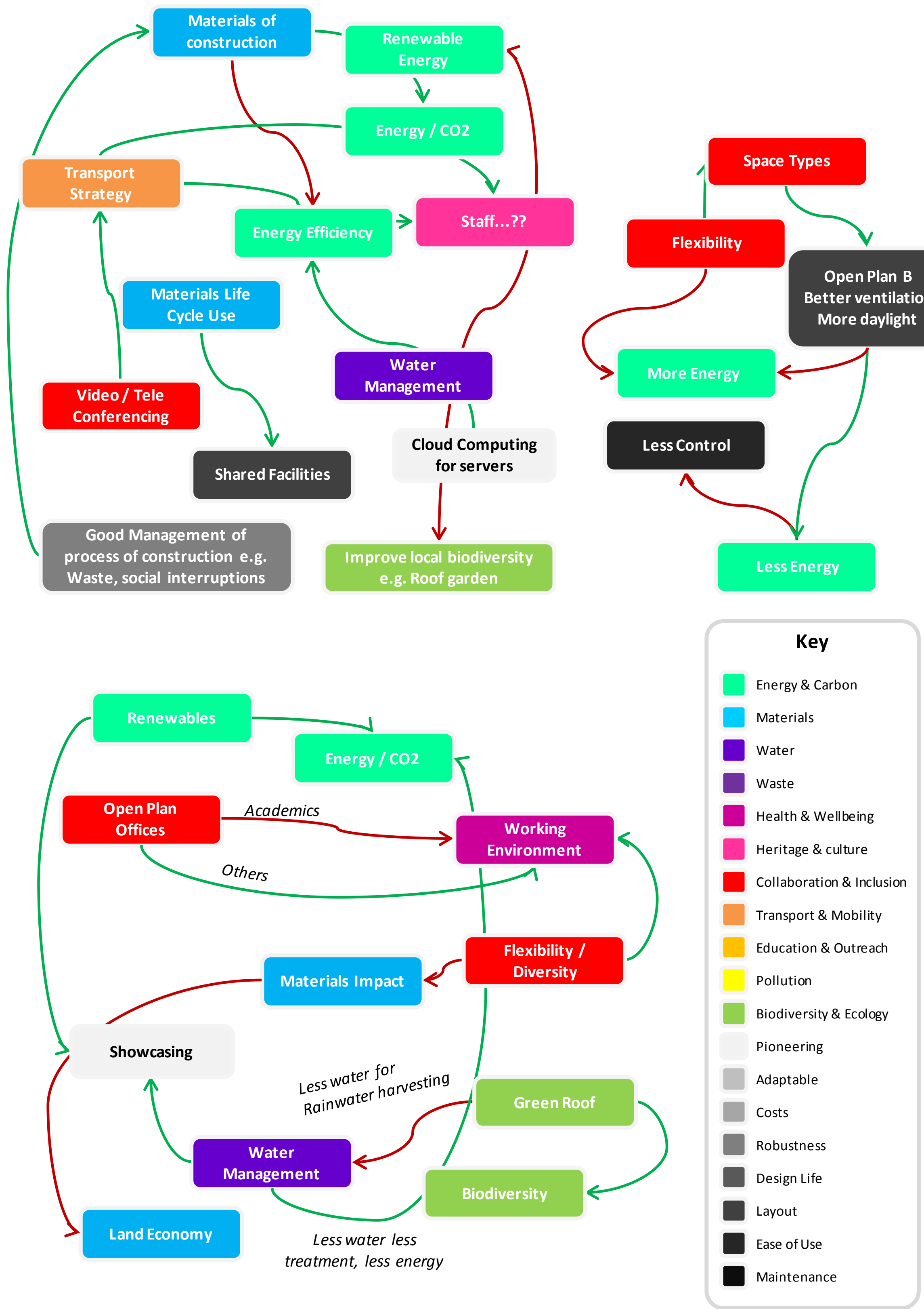


Figure 8—19 Themed output of the 'relationships mapping'

8.5.6 Stages of the sustainability process – managing and reporting

In the groups the following questions were asked and notes were taken on the discussion by the facilitators:

- *Who should own / manage / be responsible for the framework at different stages of the project?*
- *How do you foresee the framework being implemented?*
- *What are the external requirements required by the framework?*
- *How should this be related to standard environmental assessment methods e.g. BREEAM?*
- *How do you foresee a bespoke approach offering a robust and valid process?*
- *What do you consider to be the benefits of a bespoke sustainability framework?*

Each facilitator took notes during the sessions, which were captured and included in the summary report. Key themes and conflicts emerging from the different groups are shown below.

Key points raised by multiple groups include:

- The requirement to achieve independent recognition / verification – whether this is through an external audit process or through some other method of achieving recognition, such as awards.
- Robustness to external criticism, including the need to achieve independent recognition and verification was consistently important. Options suggested for this include independent 3rd party audit, achievement of design awards, and the use of audit trails and recognised standards for accountability (such as timber certification schemes).
- The need to ensure the framework transitions from design to occupation smoothly and is managed throughout.
- The importance of external reporting and communication, to demonstrate to funders and stakeholders, as well as other interested parties.

Areas where groups' views conflicted include:

- Implementation of the framework – some groups preferred that the design team manage and implement, others see tenant involvement as more crucial, and others see that responsibility needs to lie with estates as building owners.

- Thoughts around BREEAM – some groups considered that the robust process and recognised standard would be beneficial to the project, and that the risks of not using BREEAM were great, others considered that sustainability assessment systems were time consuming and the money / time would be better spent improving the ‘actual’ sustainability of the building.

8.5.7 Feedback

At the end of the workshop participants were asked to fill in a feedback questionnaire to capture their thoughts on the process. The feedback questionnaire was aimed to establish the success of the workshop. Questions were designed collaboratively between the researcher and the other Buro Happold facilitators. The intention was that the questionnaire would be quick to fill in, and also allow them to comment on how successful they thought the workshops were.

As the questionnaire was only circulated to the attendees of the workshop, it was considered that a combination of open questions and closed questions was appropriate. One closed question was used asking, *“How successfully do you feel we have managed to capture and discuss the sustainability perspective of your group in today’s workshop? Please circle below.”* An eleven point answer scale was then used which ranged from 0 (not at all) to 10 (completely). Comments were also encouraged with respect to this question. Other questions were open ended questions regarding efficiency and effectiveness, most relevant/irrelevant parts, and suggestions for improvement of the engagement session. A final answer box was provided for specific comments or questions. If leaving comments or questions that required follow up, stakeholders were also asked to provide their email address. The questionnaire was designed to be completed in less than 5 minutes which was considered important at the end of a long day. The questionnaire was checked and trialled internally before the workshop.

From the people that attended 12 responses were collected. If the 5 facilitators from BH are excluded then this represents a response rate of 50%. Some people had to leave the session early but the response is considered appropriate to use for the session.

A copy of the questionnaire used is provided in Appendix H. All comments from respondents were transcribed, anonymised and circulated to the wider group, again in order to be transparent about the whole process. A summary of the feedback is discussed below.

The average feedback score from 12 responses was 7.8/10. This is considered positive feedback with respect to how well the groups' sustainability perspective was captured. There were comments detailing that the sessions were "well-structured and administered" and that there were "clear targets and session structures". There were comments from different individuals stating that it was "very interesting, in introducing different user groups and allowing them to discuss and see potential similarities and differences," and that "it was good to ask for our opinions and values." Whilst none of the facilitators were trained facilitators, some participants commented that "sometimes the facilitator [was] voice heavy (but perhaps quiet / indecisive groups fault!)." This should be noted as a potential limitation. However, other participants commented that the "facilitators did a good job". Another participant considered that it was "a very engaging day of discussions to establish the high-level ambitions." One participant commented that the success, "varied from exercise to exercise! Fewer exercises but more time for each could have worked better".

With respect to the question, "*How efficient and effective do you feel the workshop has been?" There was general consensus that it was well run and time efficient with comments from different individuals including "well run time-wise, clear goals", "very time efficient"* and *"very efficient in getting a lot of information on the table".* With respect to efficacy, there were some comments stating that some participants found it effective, such as "Very effective" and "good – effective and efficient". However, others wished to reserve judgement on the effectiveness of the sessions, stating that "effective – time will tell" and "… the effectiveness will be seen at the circulation of the report, design and use". Another participant felt that, "they learnt a lot, but the sessions had too much overlap so the event could have been 3 hours rather than 5".

Participant responses with respect to the questions, *"Which parts did you find least interesting/irrelevant?"* were focused around the ranking exercise, which focused on prioritising issues. Comments included the *"ranking exercise – less relevant"* and the, *"session that asked us to rank"* and *"too much emphasis on prioritisation".* There were other comments around some repetition of the afternoon and morning sessions.

With respect to comments on *"… how we can improve the engagement session?"* two were received with respect to improved prior guidance. One participant commented that "longer needed for summing up time of each feedback from groups". Interestingly, one participant commented that, *"we should have focused on outlining objectives for achieving a sustainable work place. Slightly wary of project team for defining these objectives for us."* This was considered surprising by the facilitators, as the whole session was focused around understanding their perspectives and sustainability objectives for the project.

Other comments included: "Thank you – I thought this was an interesting and valued session…" and comments around *"excellent facilitation."* Two comments were also received with respect to the provision of more detail to help them make decisions such as *"it would have been good to gain a broader overview of possible sustainable interventions…*" and *"more details would have been useful to help us make decisions / see things differently"*

On the whole, the feedback was positive, however some feedback on improvements was considered when refining the techniques for use on Case Study 1C.

8.5.8 Development into sustainability framework

The themes emerging from the workshop were then used to inform a bespoke sustainability framework for the project. This was not done by the researcher due to time constraints, but instead done by a sustainability consultant in the sponsoring organisation. The output of the workshop provided the key themes on which this was based. Images showing the themes and the development of the sustainability framework are included in Figure 8—20, Figure 8—21, and Figure 8—22.

	Aim	Motivation
BIODIVERSITY & ECOLOGY	Improve local ecological value and urban biodiversity. Support building users in their work to improve and publicise the impacts of global conservation work.	As species are lost so too are our options for future discovery and advancement. Impacts of biodiversity los include vulnerability to natural disasters and greater effects from global warming.
COLLABORATION & INCLUSION	Maximise the achievements which can be made by the building and its occupants through encouraging collaboration within and across user groups, and allowing the building to be accessed by all.	A collaborative working environment will foster creativity, unlock opportunities and increase productivity. An inclusive environment allows everyone to achieve their potential.
EDUCATION & OUTREACH	Allow the refurbished building to support the users in achieving maximum educational potential. Enhance information transfer within the construction industry to allow others to learn from the project.	Educating building users and visitors about energy use, the natural and built environment, zoology and conservation will support sustainable development locally and worldwide.
ENERGY & CARBON	Through the design, construction & operation of the refurbished building, demonstrate reductions in demand for energy, improvements in efficiency of energy use & supply of energy by low carbon means.	Energy generation in the UK comes primarily from fossil fuels, which when combusted release carbon dioxide. By reducing energy consumption we can improve energy security & reduce CO_2 emissions
HEALTH & WELLBEING	Create an environment which maximises building user wellbeing and enables occupants to make healthy choices. Minimise any negative impacts of construction on the local neighbourhood.	Healthy and happy people are more productive in the workplace, and more beneficial to society as a whole.
MATERIALS	Reduce negative environmental and social impacts arising from specification of new materials, through reducing material use and supporting companies which are developing sustainable materials options.	There is an inherent limit to the amount of materials available on the planet; Procurement of materials also has impacts in terms of economic and social impacts of the supply chain.
POLLUTION	Reduce pollution to the local environment through the refurbishment project, including pollution to air, to ground, and to water.	Localised pollution causes health problems, damages wildlife and causes human discomfort. Local pollution should be avoided wherever possible before mitigation is considered.
TRANSPORT & MOBILITY	Improve transportation and mobility to the site. Facilitate use of low-emission and environmentally preferable transport options.	Transport consumes energy and causes local air pollution. city centre experiences huge transport problems; anything that can be done to lessen the impact should be done.
WASTE	Reduce waste generation and maximise recycling both during the construction process and during operation of the building.	Landfills take up a significant amount of space and cause pollution of the air, land and water. Recycling waste avoids the environmental impacts associated with the production of new materials.
WATER	Reduce demand for potable water in the building, exploiting opportunities to use low-grade water for non-potable uses such as WC flushing, hand washing and irrigation.	Potable water is in short supply in the south-east of England y. Much water wastage is unnecessary and can be avoided.

Figure 8—20 Key themes, aims, why bother and critical success factors for Case Study 1B[7]

[7] Taken from Buro Happold report – work not done by the researcher

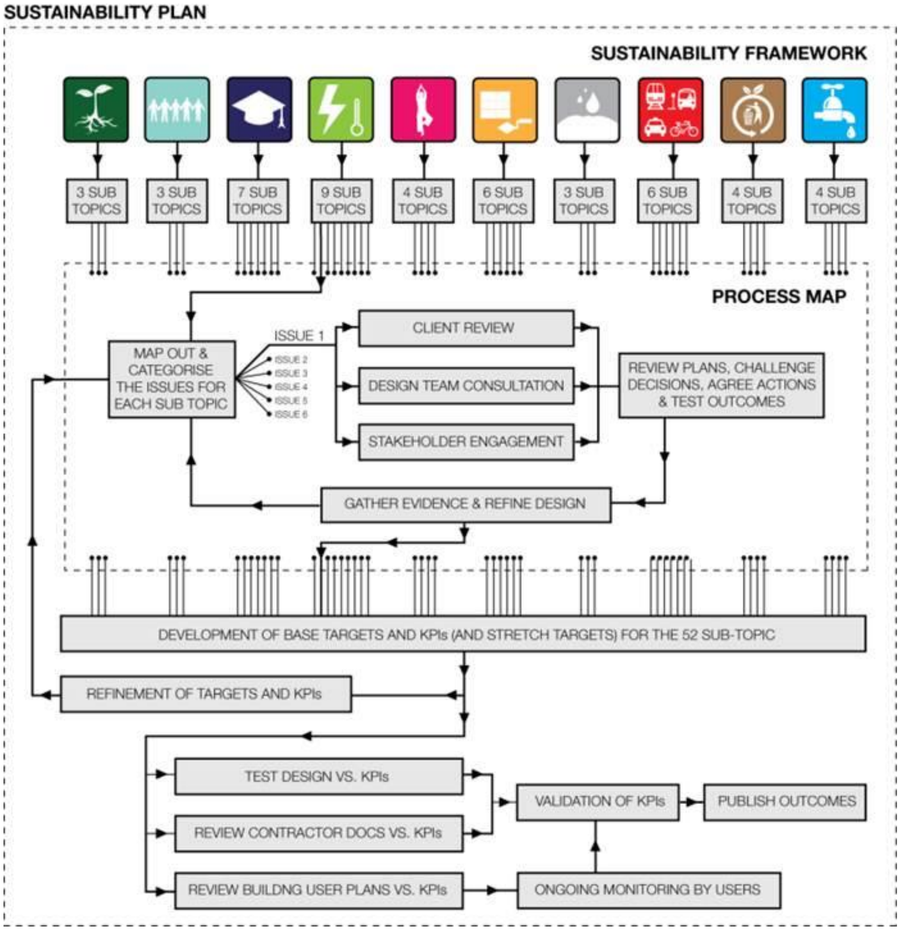
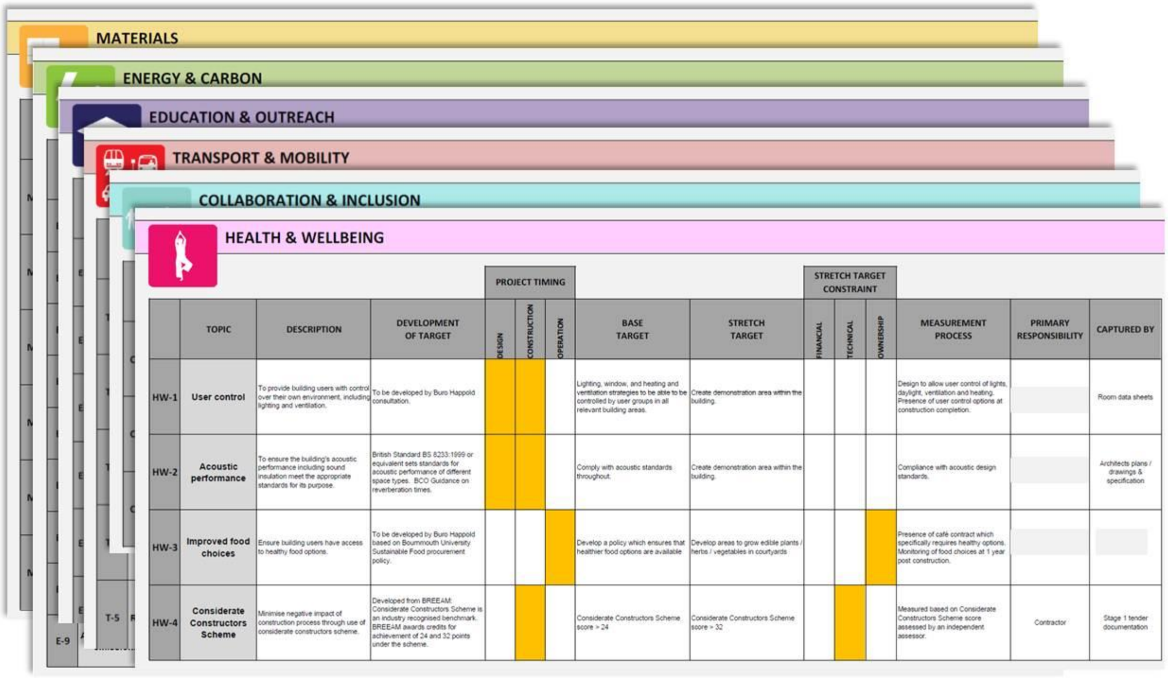


Figure 8—21 Sustainability framework and process map[8]

[8] Taken from Buro Happold report – work not done by the researcher



				PROJECT TIMING					STRETCH TARGET CONSTRAINT					
	TOPIC	DESCRIPTION	DEVELOPMENT OF TARGET	DESIGN	CONSTRUCTION	OPERATION	BASE TARGET	STRETCH TARGET	FINANCIAL	TECHNICAL	OWNERSHIP	MEASUREMENT PROCESS	PRIMARY RESPONSIBILITY	CAPTURED BY
HW-1	User control	To provide building users with control over their own environment, including lighting and ventilation.	To be developed by Buro Happold consultation.				Lighting, window, and heating and ventilation strategies to be able to be controlled by user groups in all relevant building areas.	Create demonstration area within the building.				Design to allow user control of lights, daylight, ventilation and heating. Presence of user control options at construction completion.		Room data sheets
HW-2	Acoustic performance	To ensure the building's acoustic performance including sound insulation meet the appropriate standards for its purpose.	British Standard BS 8233:1999 or equivalent sets standards for acoustic performance of different space types. BCO Guidance on reverberation times.				Comply with acoustic standards throughout.	Create demonstration area within the building.				Compliance with acoustic design standards.		Architects plans / drawings & specification
HW-3	Improved food choices	Ensure building users have access to healthy food options.	To be developed by Buro Happold based on Bournmouth University Sustainable Food procurement policy.				Develop a policy which ensures that healthier food options are available	Develop areas to grow edible plants / herbs / vegetables in courtyards				Presence of café contract which specifically requires healthy options. Monitoring of food choices at 1 year post construction.		
HW-4	Considerate Constructors Scheme	Minimise negative impact of construction process through use of considerate constructors scheme.	Developed from BREEAM. Considerate Constructors Scheme is an industry recognised benchmark. BREEAM awards credits for achievement of 24 and 32 points under the scheme.				Considerate Constructors Scheme score > 24	Considerate Constructors Scheme score > 32				Measured based on Considerate Constructors Scheme score assessed by an independent assessor.	Contractor	Stage 1 tender documentation

Figure 8—22 Example development of the sustainability framework[9]

The bespoke sustainability framework has been used on the project instead of BREEAM, as it is considered more representative and relevant to the existing building refurbishment. The Head of Estate Planning commented that, *"working collaboratively with various University stakeholders… which will occupy part of the building when the work is complete, they have robustly embedded the sustainability plan in the project and are continuing to do so through on-going consultation."*

8.6 Case Study 1C

Some of the tools and techniques were also applied on another project as part of the action research methodology undertaken through Case Study 1C, which was undertaken after Case Study 1B. This involved engaging 24 stakeholders in relation to a European Funded RIBA Stage C/D design of a new college and multi-use conferencing space, which would teach courses relating to sustainability. Of these 24 stakeholders engaged, 10 were members of the design team.

[9] Taken from Buro Happold report – work not done by the researcher

Whilst the approach and analysis techniques were similar, modifications were made for the given context (which included a different structure of workshops) and to reflect on the feedback that was given in Case Study 1B, and also fit the time requirements for the project. This was considered part of the Action Research Process and also reflects real world research where methods and approaches have to be flexible and orientated to the need of the client (Robson, 2002). Three workshops were therefore conducted for Case Study 1C. These were called the *'Engage'*, *'Understand'* and *'Define'* workshops. These are detailed below.

8.6.1 Engage Workshop

The first, 'Engage' workshop, which aimed to enthuse the stakeholders and initially provoke thought, before focusing on the needs of the college and what the project was trying to holistically achieve. The workshop agenda was developed in collaboration with one of the Directors of the sponsoring organisation with significant industrial experience. Initially, attendees were introduced to methods of understanding, defining, doing, measuring and being sustainable. Then some questions were posed for the stakeholders to consider prior to the next workshop. This was based in the spirit of "Pecha Kucha", a technique where presenters present 20 slides with slides timed to move on after 20 seconds, the idea being to keep things fast past and concise (Klentzin et al., 2010). In a similar spirit each stakeholder representative was asked to give a presentation of no more than three minutes on what a sustainable design for the building was from their perspective. This was then discussed in relation to the project in small groups, before being presented back to the larger group. The engage workshop was structured to address comments from the feedback from Case Study 1B that, *"prior guidance could have made the workshop more effective"* and also reflected comments *" It would have been good to gain a broader overview of possible sustainable interventions that are extant of work; examples which could help our thinking."* Additionally, the Director of the sponsoring organisation, who was leading the project, also wanted to give stakeholders time to consider sustainability before capturing their thoughts in the same format as Case Study 1B.

8.6.2 Understand Workshop

8.6.2.1 Methods

The follow up, "Understand" workshop additionally had to be conducted in a two hour period, which was a significant reduction on Case Study 1B. However, some of the feedback from 1B stated that some sessions were seen as repetitive. Therefore, the "prioritisation of key themes session," was removed as many considered that there was too much emphasis on prioritisation at that particular stage of the process in Case Study 1B. This is an issue outlined by Keeney (1992), who explains that emphasis on prioritisation without consideration of the costs of achieving different levels of performance can be misleading. Having said that it was considered a useful thought process to maintain some elements of prioritisation, which could also be updated or modified as more information becomes available and the design progresses.

The different amounts of time allocated to this workshop in comparison to Case Study 1B for different projects again shows the constraints of working in industry and the need for an approach which is relatively flexible and able to adapt to the project's needs. The researcher planned this workshop, however was not able to attend and facilitate the "Understand" workshop. However, facilitators for the workshop were briefed by the researcher on the methods that should be used and also given facilitation packs similar to that used on the previous case study project. All analysis was done by the researcher. This was possible as the outputs of the session had been captured through photographs and collection of the output of the sessions which included the sheets produced through the workshop session. This was then checked by another sustainability consultant who was leading those elements of the project that it was representative from their perspective.

The four most successful techniques from Case Study 1B were utilised in the workshop, which included:

- A sustainable building is… (see Section 8.4.1)
- Opportunities vs, constraints (see Section 8.4.2)
- Importance vs. influence of the design team (see Section 8.4.4)
- Relationship mapping (see Section 8.4.6)

These were structured to be four, thirty minute sessions due to the shorter duration of the workshop. In order to reduce the length of each session, the summaries back to the rest of the group after each session were removed in Case Study 1C, for practical time restraint reasons.

8.6.2.2 Results

The results for the application of the following approaches are included in Appendix J.

8.6.2.3 Feedback

The same feedback form was circulated as discussed in Section 8.5.7 except with the addition of one extra question focused around how comfortable people felt to share their view and opinion. This feedback form is included in Appendix H and the full results are shown in Appendix K. A summary of the feedback is discussed for each question below.

How successfully do you feel we have managed to capture and discuss the sustainability perspective of your group in today's workshop? 0 (Not at all) – 10 (Completely)

The average score from 5 responses was 6.6/10 (from five responses), which is a worse score than received on Case Study 1B. However, the response rate was poor, and additionally the context was quite different. One participant commented that it was *"difficult to define sustainability when the building's use hasn't yet been defined".* This reflected the stage of the project, and that there wasn't a clear brief for the project at the time. Another participant said that *"we lost our way a little in the middle two sessions"* as they were still thinking at a very high level. And another commented positively that there were *"lots of ideas".*

I felt comfortable to share my view and opinions. 0 (Not Comfortable) – 10 (Very Comfortable). This received an average response of 9.2/10 from 5 responses, which suggests that the right kind of environment was established for people to share their views and opinions.

How efficient and effective do you feel the workshop has been?

The workshop was generally considered efficient and effective with people commenting that it was "well timed and facilitated", and that the session "a sustainable place of work is…" was very useful in providing new ideas and seeing commonality of thought." Additionally, the same participant considered that the Relationship Mapping exercise, "led to very useful and interesting discussion" and another commenting that the workshop was "very useful".

Which parts did you find least interesting/irrelevant?

In terms of aspects considered least interesting two comments were received that said that all the sessions were important and interesting. However, the influence vs importance aspect was considered difficult as "all seemed very important". One commented that the "Relationship mapping exercise" based on group model building was least interesting and another that importance vs. influence was least interesting.

Have you got any suggestions on how we can improve the engagement session?

Whilst one person responded that they had no suggestions on how the sessions could be improved there were four comments relating to improving the sessions. Three of which were around providing a better context for the project. However, it should be noted at the time that the brief was in flux and that there was a lot of uncertainty around what the project was going to be. Thus, information on the project was very limited. Another comment was received in relation to the short time periods for each session with them commenting that "a bit longer to discuss would have been helpful".

Please leave any other thoughts, opinions or specific questions regarding anything discussed in the session below (if you have specific questions please leave your email address so we can get back to you).

With respect to this, one attendee commented that they, *"would have liked to have seen other groups output at end of each workshop but appreciate that this would have been time consuming."* This was removed from the sessions due to the short time period, and also the impractical layout of the facilities to be able to do this. For example, due to the size of the rooms, the groups were split into several areas and thus feedback would have required reconvening in a bigger space.

8.6.3 Define workshop

The final define element was to present back the results and the key themes that had emerged to the project's design team workshop. This involved running through the analysis and what had emerged as important with the design team. There was general agreement that the themes were representative of the project and that if the project was taken forward past design stage D that they would be developed into a project sustainability and value framework.

8.6.4 Summary

Case Study 1C was again considered successful in defining themes that were important from a sustainability and value perspective and received positive feedback from both stakeholders and the client. This was captured through dialogue with the project manager and also an email from other project representatives. Feedback from those involved in the sponsoring organisation who reviewed the work also considered the approaches to be successful in better understanding sustainability and value for the project.

8.7 Discussion

In both action research case studies 1B and 1C, the stakeholder participation methods when applied in workshops with stakeholders, identified a more holistic range of sustainability considerations than those covered in traditional environmental assessment methods. For example, the themes of BREEAM (as shown in Figure 8—7) were further added to and considerations were across a broader range of issues, covering the environmental, social and economic elements of sustainability.

The different output of the two workshops, i.e. the different emerging themes and repetition of themes from the two case study projects, demonstrates that sustainability and value defined from a normative perspective varies across projects and that if sustainability considerations are going to be considered of value, then they have to be considered within the project context. This is a different approach to applying BREEAM with its fixed considerations and weightings. Different techniques used in the workshops, also tended to achieve different considerations with respect to sustainability. For example the opportunities and constraints analysis, based on the force field analysis (Lewin 1952), was good at eliciting considerations such as costs and budget, which were typically less considered in the “A Sustainable Place of Work is…” exercise. Additionally, this exercise allowed the extended thoughts of the stakeholders on how such opportunities could be exploited or constraints weakened, which might not have been known to the design team. Workshop sessions aimed at understanding what was important in relation to what the design team had influence over, were considered useful by the design team, and allowed an understanding of stakeholder expectations.

The *"relationship mapping"* approach looking to identify potential conflicts and win-wins through considering the relationships between different considerations was also seen as useful by attendees in the workshop held in Case Study 1A in Section 7. Additionally, in the workshop of Case Study 1B, feedback from some participants on the day was that prioritisation was less key and *"cross links and synergies are more important"*. Additionally, practitioners stated how the techniques were useful when the approaches and associated results from the case study projects were presented back to practitioners in the sponsoring organisation.

The feedback from the workshop surveys with respect to the process was also generally positive. Interestingly however, the second action research case study (1C), was scored lower by the project stakeholders with respect to how successfully we had managed to capture the perspectives of the group, even though the process had been modified to account for feedback from the previous workshop in Action Research Case Study 1B. However, this could be due to a number of reasons. The feedback was obtained after the second "understand" workshop, which the researcher was unable to attend. The facilitators, whilst briefed, did not have the researcher who had developed the techniques there on the day. The importance of a skilled facilitator is highlighted by Reed (2008). Additionally, the layout of the facilities was not ideal, as groups were in different rooms, therefore getting feedback from across groups was more difficult.

As the workshops sessions provided a small amount of time at the end of each session for groups to summarise the key points, it is considered that there was a checking mechanism to ensure that the facilitators had captured what was important. In Case Study 1B, this also included time for each group to summarise back to the other groups in the room as well. Unfortunately due to time restrictions and the layout of the facilities this had to be removed from Case Study 1C. Additionally, the output of the workshops was always circulated back to attendees with the opportunity for them to comment if they thought that their thoughts had been misrepresented.

The further testing of the approaches would be beneficial in a similar way to that undertaken by Tippett (2004) in the development of DesignWays. This included pre and post workshop interviews with participants. However, the techniques developed through this research allowed the main sustainability themes to be transparently identified and circulated back to stakeholders with opportunity for them to comment if they thought the output was unrepresentative. No comments were received. The following overarching discussion section for this part of the thesis (Section 9) considers how the research addresses the original research questions for this part.

Further discussion on the reliability, validity and generalisability of the approaches is included in Section 16.

8.8 Conclusion

This section has developed and tested engagement techniques to capture stakeholders' values and thoughts with respect to sustainability on building projects. Techniques were developed for application in workshops, through considering the problem structuring methods in the literature, and wider systems and stakeholder engagement techniques. Action Research Case Studies 1B and 1C were undertaken with the sponsoring organisation on two client projects. These projects were undertaken sequentially, with the learning from Case Study 1B used to refine the techniques for application in the workshops in Case Study 1C, thus allowing a second learning loop of action research.

The next section, discusses the learning from all the techniques developed through action research aimed at understanding the values and sustainability perspectives of project participants and proposes a set of techniques for application on projects.

9 Part 1: Discussion

9.1 Introduction

This section discusses some of the techniques developed and tested through considering the processes and the outcomes of the techniques. It considers how the techniques relate to the research questions and objectives defined in Section 5.2.

9.2 Overview of Part 1

The work has built upon areas requiring further work as identified in the literature review. A number of engagement techniques have been developed through action research and applied on three action research case study projects. The techniques are aimed at defining what should be achieved beyond the minimum standards required for the region such as meeting legislation or mandatory planning standards. They are intended to be defined as aspirational aspects of the project.

Through the action research case study projects a number of data collection methods have been applied, which include questionnaires and workshops based techniques that are structured and provide output that is useful in the definition and implementation of sustainability and value on projects. Essentially, these provide what Reed and Gordon (2000) refer to as process case studies, something that they state is required in the construction industry. Additionally, it is considered that they address the areas of, systems thinking and analysis, understanding the process, and good communication, identified as areas with limited work by Cole (2000). Such commentary from the literature was an influence in choosing the action research methodology and case studies as a data collection method. Additionally, in doing this it was considered that the researcher would have to directly grapple with some of the challenges of the design process outlined in Section 2.3.3 in terms of the messy, ill-defined nature of the early design process (Green and Simister, 1999) and the highest opportunity for sustainable design and value being at the start of the design process (Reed and Gordon 2000, Bourke et al. 2005), where there is typically the least information.

The following is a discussion of the process and the outputs across the three case studies, which involved numerous data collection techniques as shown in the Table 9—1. This highlights the multi-method approach that was advocated by AlWaer et al. (2008) and Alwaer and Clements-Croome (2010) and also important in ensuring valid results, as discussed in Section 16.6.

Table 9—1 Data collection methods for Part 1 of the research

Data collection method	1A	1B	1C
Literature review	✓	✓	✓
Collaborative development of techniques	✓ Internal Trial Questionnaires / Workshops and dialogue with professionals with refinement of techniques based on feedback	✓ Development of techniques based on literature and dialogue with practitioners	✓ Development of techniques based on literature and dialogue with practitioners
Questionnaire	✓	×	×
Workshop observation	✓	✓	✓
Workshop output	×	✓	✓
Workshop Feedback Forms	×	✓	✓
Internal Review with practitioners	✓	✓	✓
Internal Feedback	✓	✓	✓
Informal Client Feedback	✓	✓	✓

The questionnaire data collection method included the two part questionnaire that is partly based on the Schwartz Values Survey (Schwartz and Mark, 1992), but also asks questions to stakeholders in relation to the importance of project requirements, to get a feel for which areas are considered important by stakeholders. The questionnaire was chosen as a data collection method as it could be circulated to a large amount of people quickly and the results could also be analysed quickly. Additionally, group think would be mitigated and the influence of politics and power structures on the results would be minimised.

The technique was considered useful, in the application on the internal trial projects as well as the action research case study project, by participants. Additionally, it was considered a unique and novel approach with demonstrable benefits to numerous people that it was presented to and discussed with in the sponsoring organisation, which included the senior partners of the organisation. Comments included, “that gathering information on the high level values and combining this with approaches aiming to understand more specifically the project requirements, offers insights into what stakeholders value at a much better detail than is typically considered on projects.”

The approaches and anonymised results have been used in bid material within the sponsoring organisation as best practice techniques to better understand value from a project perspective. They have also been published on the company’s website and a capability statement has been developed around learning from applying such techniques.

Techniques aimed at allowing the stakeholders more say in defining what was important to the project were also considered appropriate. However, doing this in a questionnaire format was not considered appropriate for the following reasons:

- open ended questions do not generally get a good response rate
- there is not the opportunity for two way dialogue and clarification of points
- there is no face to face contact to establish trust and it is not possible to further explore ideas.

Workshops allow dialogue to explore ideas in more depth, which is not possible through a questionnaire alone. Additionally, they aligned with the workshop based approaches typically used for PSMs, which the literature advocates are good for integrating stakeholder knowledge (Khadka et al. 2013).

Ideally, from a research perspective a combination of techniques would be used to provide a combination of data collection to better define value and sustainability in the project’s context, as each tool / method has its advantages and limitations. This is shown and discussed in Figure 9—1. This image demonstrates that all the stakeholders engaged are not likely to be all the stakeholders of the project and thus a full range of views is unlikely to be achieved. Techniques such as questionnaires are good at potentially gaining a wide range of views and opinions quickly, but at the same time the depth of understanding received may be relatively shallow. For example, it may allow for identification of a trend, but not why that trend is occurring.

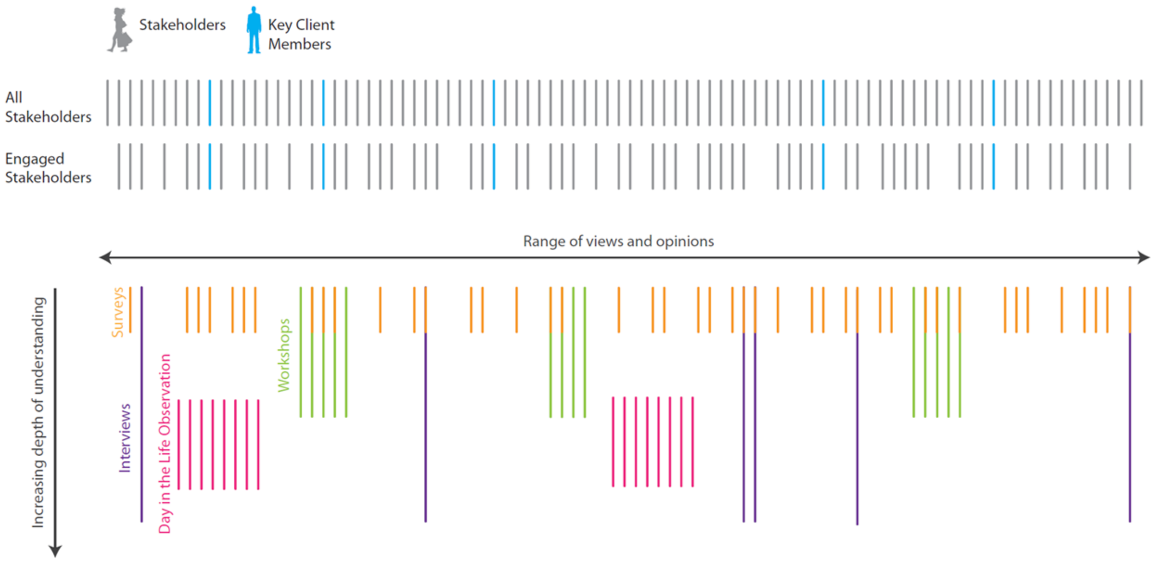


Figure 9—1 Range of views and opinions on value vs. depth of understanding

Therefore, ideally a combination of approaches would be applied; however, in reality this may not be possible. Key project stakeholders may have a preference for one type of approach over another, or time limitations may mean that some approaches are unsuitable. Workshops might not be appropriate as it may be difficult to get the required stakeholders together in one place at a particular time. Negotiation and access to a large number of stakeholders that are key to the project proved difficult on this project, with (in some cases) significant amounts of time passing between workshops. Additionally, it may be seen as an expensive exercise to do so. A survey is much cheaper and easy to analyse than the output of a workshop and therefore may be more applicable in some situations. However, some stakeholder groups may not respond well to a survey without having met in a workshop format first. Figure 9—1 also considers possible other approaches to understanding the perspective of stakeholders including interviews. However, it was considered that interviews across many stakeholders would be too time consuming to conduct on a project by project basis and thus interview techniques were not employed in this research.

Emerging from the action research case study work are a set of techniques, which include a method of structuring a questionnaire and a set of workshop techniques to better elicit what represents sustainability and value to a group of stakeholders in the project context. These are shown in Figure 9—2. These techniques each have their benefits and will be discussed in relation to how they address the research questions in this section. However, it is important that they are not seen as just a set of tools for participation, as Reed (2008) explains the emphasis should be on participation as a process. Reed (2008) explains how the process needs to be underpinned by appropriate philosophy and considers how to engage the relevant stakeholder at the most appropriate time.

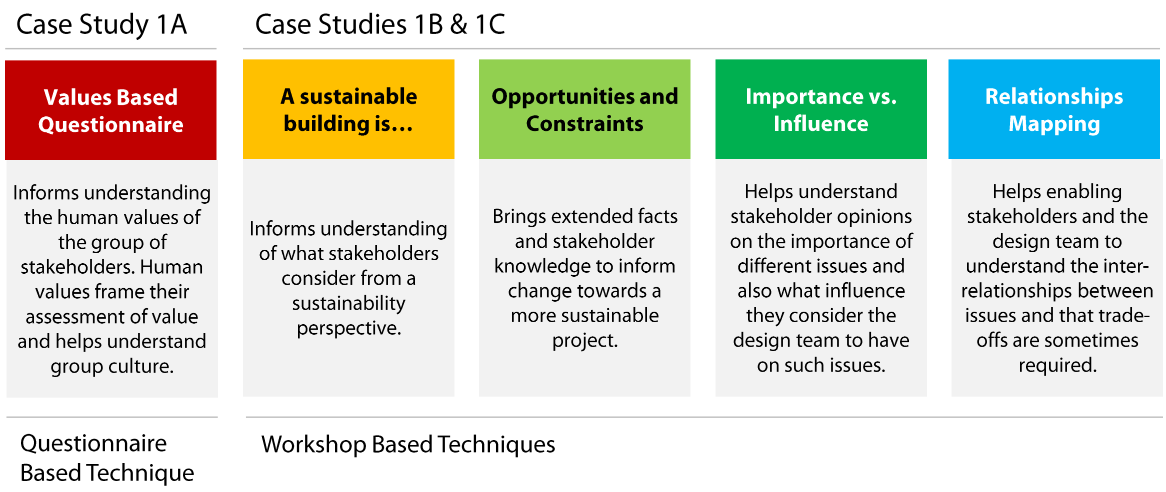


Figure 9—2 Techniques developed and refined through Part 1 of the research and their purpose

Ideally, such a process would involve utilising all the above engagement methods, sequentially from left to right. They all have different objective in providing a richer understanding of sustainability and value from project stakeholders and have the overall purpose of informing the decision objectives for a construction project. However, as has been the case through this research, getting project stakeholders in a room at the same time has been challenging, and it has been difficult to get stakeholders together for long enough to be able to work through all the techniques. Therefore, in some situations it maybe that only one or two of the above techniques can be implemented under the project's constraints. In Case Study 1A, the focus was on the "Values based questionnaire", with a follow up workshop that also demonstrated how the values mapped against their requirements, utilising the "Relationships Mapping" technique. Where as in Case Studies 1B and 1C, there was a focus in the four workshop based techniques, however, the speed of which the project came round and a preference from the client to use workshop based techniques, meant that a survey based approach was not possible to apply on Case studies 1B and 1C. Additionally, at the time, Case Study 1C did not have a strong brief on which to take requirements and develop them into a survey.

Whilst all the techniques have not been applied on a singular project, it is considered that this would provide a more complete picture of the project stakeholders' sustainability and value perspectives. It is considered that further work could test the application of all techniques on a singular project. Additionally, with respect to the order of the above techniques they have only been tested from left to right. This is important, for example, the "Opportunities and Constraints" exercise first relies on participants being able to consider "what a sustainable building is" as the goal that they are aiming to change towards. This is an output from the "A Sustainable Building is…" exercise. The exercises of "Importance vs Influence" and "Relationship Mapping" would also be considered difficult to undertake without undertaking the, "A Sustainable Building is…" exercise. Additionally, whilst not tested, it is thought that considering the relationships between requirements and interventions through the "Relationship Mapping" exercise, benefits from being at the end, as it is considered by the researcher to be the most complex for both facilitators and participants in that it requires the facilitator to also take a more active modelling role. Other exercises also feed in information, which is useful in the "Relationship Mapping" exercise.

A more in-depth, overarching approach is not considered appropriate as all three case studies have also employed different techniques based on time available, the stage of the project and the perceptions of the client and stakeholder groups. Therefore, it is considered some flexibility is required when applying the techniques in practice. In fact, it is intended that further work should explore which combination of approaches work best together, and also further work should further test the efficacy of the approaches. It is however, considered that the “A sustainable building is…” approach, combines well with “opportunities and constraints” approach. As the output from the former can be used as a basis to structure the opportunities and constraints approach.

The contribution of this area of work undertaken in Part 1 of this thesis is in the development and testing of the techniques through action research, in collaboration with industry professionals in defining sustainability and value for construction projects. However, Reed (2008) emphasises that the quality of decisions made through stakeholder participation is strongly dependant on the nature of the process leading them and it is the deficiencies in the process that are most commonly blamed for failures that lead to disillusionment in the process. Reed (2008) continues to explain that this arises from a focus on the tools of participation, rather than the process within which those tools are used. Therefore, the process in which the above tools should be selected and used should consider the 8 features identified for best practice participation outlined by Reed (2008) (see Section 4.3.1.).

9.3 Review against research questions and objectives

The questions that Part 1 of the thesis addresses were developed through considering the research gaps in the literature as shown in Figure 5—2 and discussed in Section 5.2.The questions are as follows:

- Is it feasible to develop stakeholder participation techniques to engage project stakeholders in defining sustainability and value themes on which to base design decisions in the building design context that:
    a) Integrates stakeholder values and preferences?
    b) Integrates environmental, social, and economic value?
    c) Integrates stakeholder knowledge rather than considering purely expert knowledge?

These questions were addressed through two research objectives:

- To develop and test a set of stakeholder participation techniques to define sustainability themes for a project’s context.

- To address the challenges of integrating sustainability into the design process in the building industry.

These objectives were addressed through the action research process that was used to identify particular techniques from the literature and develop and utilise some of these techniques with industry professionals before testing them on projects. The process of doing this in an industrial context, working with engineers in the sponsoring organisation, was instrumental in ensuring that they were fit for the project's context. With respect to the process of using the techniques, feedback from stakeholders involved was positive. The output of the techniques also demonstrated a broad set of sustainability and value themes that stakeholders considered to be representative. All the techniques developed and presented here were utilised in a live project environment and received good feedback through the questionnaire and informally through the project managers. Therefore, they are fit for purpose as they have actually been applied in the context that they are intended to be used and demonstrated to be useful in identifying a wide range of value themes from stakeholders. The feedback on the process and the outcomes demonstrates the feasibility of developing the techniques.

The remainder of this section considers how the techniques developed address the objectives, which in turn answer the research questions.

This was initially explored through the literature review, and key areas requiring further work were identified. This considered a review of techniques currently used in the construction industry, which primarily had an environmental focus, but also considered techniques such as design quality indicator (DQI) (Gann et al., 2003) and the value in design (VALiD) approach (Austin, 2005).

The integration of stakeholder values, needs and preferences is argued as important by Kaatz et al. (2005) and Kaatz et al. (2006) with respect to building sustainability assessment and also more broadly by authors such as Ratner (2004) and Kates et al. (2005). Despite this, techniques in the industry do not generally account for such stakeholder engagement on building projects. Kaatz et al. (2005) present a theoretical justification for modifying sustainability assessment to include broader participation of stakeholders. They conclude that the very act of participation grounds the process and project in the local context and allows assessment to reflect the local needs, socio-cultural, economic and biophysical contexts. This is also shared by Mathur et al. (2008), who state that meaningful stakeholder engagement can be seen to enhance inclusive decision making, promote equity, enhance local decision making and build social capital. All these are essential for sustainability. They also promote the view that stakeholder engagement can also be an opportunity for social learning.

The techniques developed acknowledge that there is a subjective element to sustainability and that like value; sustainability will be defined and judged differently depending on the values of the stakeholders. However, it also considers that whilst stakeholders can define what is important, there will be many aspects of performance that can be measured scientifically. This part of the thesis is concerned with the former aspects of defining sustainability. However, it was also considered important to consider both sustainability and value together based on literature which emphasises the importance of value in the construction industry (Egan, 1998, Cole, 2000, Austin et al., 2005b, Gann et al., 2003, Mills et al., 2006, Thomson et al., 2003, Bourke et al., 2005). All of the above authors mention the need to engage stakeholders in the definition of value and many others advocate for engaging stakeholders with respect to sustainability (Mathur et al., 2008a, Reed, 2008, Reed et al., 2006, Kates et al., 2005, Kaatz et al., 2006).

Therefore, techniques such as the values based questionnaire along with project specific questions on requirements, is considered to be one way of assessing the values of the stakeholders of a group. By undertaking such an approach, whilst also considering the stakeholders opinions on the various requirements of the group, a better understanding of what frames value for the group of stakeholders emerges and the design team can start to communicate the value of sustainable features in those terms.

Additionally, by asking stakeholders what they think represents a sustainable building from their perspective (through the structured session), their perspectives on economic, social and environmental value are captured. Thus aligning decisions to these key themes provides a way of demonstrating how sustainable design features provide good value. Essentially, the approach provides a starting point to frame decisions on projects aligning with Keeney's (1992) approach of value focused thinking. These themes can be further developed into appropriate metrics to inform decisions. In the Case Study 1C, some participants and the client commented that the themes emerging from the workshop could be considered good or high value design. The workshops also provide the opportunity for the design team to better understand the stakeholders. Techniques such as the "Relationship mapping" exercises, allow the stakeholders to see some of the inter-relationships between requirements, and that some indeed may be in conflict. Thus they are exploring the inter-relationship between issues which is important when structuring decision objectives Keeney (1992). This is discussed much more in Part 2 of this thesis. Thus the delivery of all requirements may not be possible and consequently the approaches could be useful in managing expectations.

Furthermore, asking stakeholders to identify opportunities and constraints for moving towards a more sustainable building, brings into the process stakeholder knowledge and ways of strengthening opportunities to move towards a more sustainable and high value design. Workshop techniques, such as asking stakeholders what they think are the most important sustainability considerations, also aim to understand the priorities of the stakeholders and thus gain a better understanding of value from their perspective.

By taking the output content of the engagement techniques and using this to inform the definition of the key sustainability and value themes for a project, it is intended that these will be used to inform decision making. If decisions are based on themes that stakeholders have said are important, stakeholders will then be able to see how different design options address these themes and the value of more sustainable design options will be more obvious to stakeholders. The timeframes of this research have however, not allowed this to be reviewed and tested. Therefore, this should form further work.

Through the approaches developed, stakeholders are asked to participate in the design process. The very purpose of which is to integrate their values into the definition of value and sustainability for the project. With respect to van Asselt Marjolein and Rijkens-Klomp (2002) two dimensional categorisation, which considers the “aspiration/motivation” and the “targeted output”, The techniques are much more focused on the “process [of engagement] as a means” rather than “process as a goal”. The engagement was intended as a means to capture their opinions to be able to inform the decision objectives for the project. Thus, it has a pragmatic focus on the engagement as a means to deliver high quality decisions (Reed, 2008). In terms of the other dimension of mapping out diversity vs. reaching consensus (van Asselt Marjolein and Rijkens-Klomp, 2002), there is not strict emphasis on the techniques. Initially, they aim to capture the diversity of opinions in a format which allows people to freely express their thoughts and see and discuss that diversity openly. However, it maybe that they show a significant amount of consensus on certain issues. It is considered that these then inform the objectives for decision making for the project, with the project decision maker being able to weight different elements as they see appropriate. However, linking the engagement dialogue to the decision making in the project demonstrates to stakeholders that it is integrated within the project process and also provides incentive for stakeholders to contribute resources, creativity and commitment (Mathur et al., 2008b). The premise is that the consensus will be considered through the application of MCDA techniques which Pohekar and Ramachandran (2004) state *“provide solutions to the problems involving conflicting and multiple objectives.”*

This assumes that the stakeholder engagement techniques are meant to be used as part of an overall process that lies in between “consultative” and “collaborative” in terms of the widely used terminology of “contractual”, “consultative”, “collaborative” and “collegiate” (Biggs, 1989, Reed, 2008), but with the client representative / project manager still having overall control of the decision making process. Therefore, in terms of the categorisation of Foo et al. (2011) it would be considered a consultative approach, as in their modification of Biggs (1989) “consensus” and “collaboration” requires the decision to be jointly undertaken. Communication and integration between the design team and the stakeholders is improved through dialogue in the workshops and a better understanding of what stakeholders wish to achieve with respect to sustainability.

The themes emerging from the workshop represent those of the most discussed themes by stakeholders. At the end of the workshops, participants generally agreed that the approaches had managed to capture their sustainability perspectives and values. As discussed in Section 7.6, it is worth noting that there was some disagreement about the phrasing of the “pleasure” value on the values survey, which should be addressed as part of further work. Additionally, with respect to the success of the workshops, it should be noted that the scores on the question “How successfully do you feel we have managed to capture and discuss the sustainability perspective of your group in today’s workshop?” were different between Case Studies 1B and 1C. Case study 1B received a score of 7.8/10 and Case study 1C received a score of 6.6/10. This is a drop, even after incorporating feedback from Case Study 1B, in the techniques used in Case Study 1C. However, there are numerous reasons why this might be the case which reflect the context of the project. For example, the sessions had to be shortened due to the reduced period of time that stakeholder were available. Thus the sessions was 2 hours instead of 5 hours. Additionally, the layout of the facilities also meant that there was not the opportunity to hear what was discussed across groups in the same way that was possible in Case Study 1B. Finally, the researcher was not able to facilitate on the day, and thus had to train facilitators prior to the workshop on how to introduce and facilitate the sessions. The facilitators on the day could therefore be considered novice facilitators. The importance of highly skilled facilitation is stressed as important in numerous papers concerned with engagement (Reed 2008).

Macmillan (2006) calls for a need to open the black box of valuation and develop a methodology that could become a valuable tool to aid decision makers. He calls for a new attitude towards evidence-based design, with better articulation of values held by stakeholders, leading to more informed negotiations among them.

The values based project questionnaire builds on the work of Schwartz and Mark (1992) who developed the original Schwartz Values Survey, and then more recently of Austin et al. (2005a), Mills et al. (2006) and Mills et al. (2009), who have considered its use in the construction industry based on theory. Whilst Mills et al. (2009) used the survey across a number of construction organisations, including an architects, quantity surveyors, engineers, a value management consultancy, and a building maintenance and operations consultancy, they did not use it in a project context. They did however, state that it was useful in creating individual and organisational profiles of values priorities. They state that further research is needed to understand how values definitions processes can help individuals understand value trade-offs, reach consensus and avoid conflict.

This research builds on the work outlined above by testing it further through action research in the construction setting and considers how it could help determine project objectives in relation to value and sustainability. The result was that the survey was modified to include questions on a project specific level and then a session to consider the relationships between requirements. Essentially, considering the values of the group, which include values relating to the environment, but also a robustly defined set of human values that cover a wide range of topics. These are split into ten areas which have social, environmental and financial considerations. Therefore, it is considered that this covers the spectrum of areas covered generally under the term sustainability. With respect to value focused thinking (Keeney 1992), it could be considered that the values based questions of the questionnaire consider the broader framing of what is important to individuals, whilst the project specific questions are considering what is important to the project; essentially, they are narrowing the decisions from their strategic objectives of life as represented by their values, to the fundamental objectives for the project as detailed in Figure 9—3.

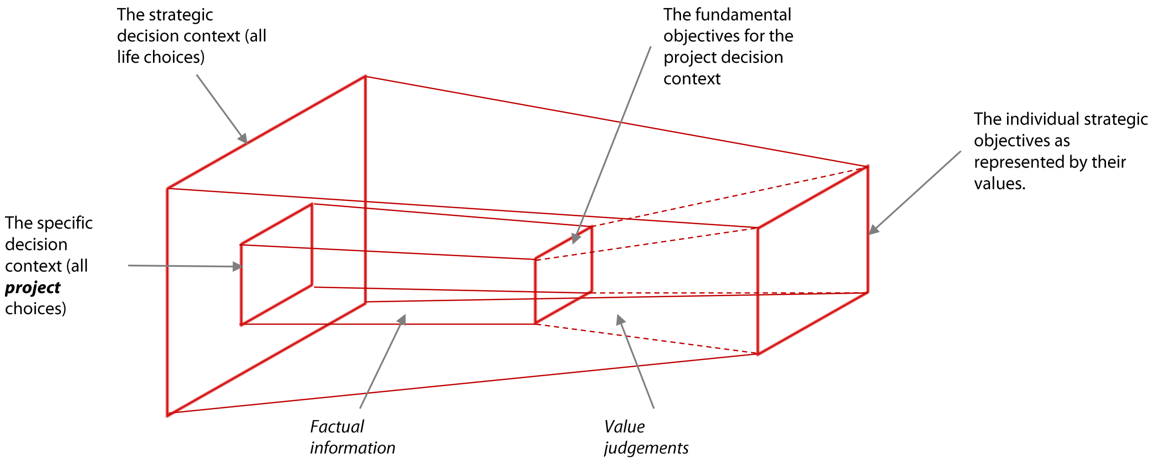


Figure 9—3 Strategic values to project objectives

The workshop technique, *"a sustainable building is…"* also encouraged and enabled the stakeholders to discuss a broad range of issues in addition to the environmental aspects as considered by many building assessment frameworks such as BREEM. Additionally, the results of the output of the sessions showed stakeholders considering social, environmental and economic aspects. Additionally, the technique takes the approach of Singh et al. (2007) that *"indicators of sustainable development should be selected and negotiated by appropriate communities of interest",* thus taking a normative approach to sustainability as discussed in section 2.2.2. Upon transcribing the output and categorising according to typical sustainability themes, as well as categorising utilising themes emerging from the workshop it was evident that environmental themes only formed a part of the overall concepts of what represented a sustainable building to stakeholders. This expands on traditional environmental assessment methods such as BREEAM and LEED.

Interestingly, however, economics was not typically a significant focus of discussion across the groups in the "a sustainable building is…" session, and this was mainly brought about through considering the opportunities and constraints to a sustainable building. Economic considerations typically emerging as the main constraints in the "Opportunities vs. constraints" session.

There is general recognition that stakeholder engagement, if designed appropriately, can provide a wide range of outcomes ranging from the capture of different forms of knowledge to social learning. Mathur et al. (2008) explain how considering sustainability as a subjective goal, which can be interpreted in a particular context through a dialogue with the context-specific stakeholders, presents a meaningful and promising way to pursue sustainability.

Khadka et al. (2013) explain that *"PSMs and wider problem structuring action may help utilise and combine the local, historically and culturally grounded practical knowledge with expertise of resource managers and professionals"* Techniques were developed based on problem structuring methods with inspiration taken from interactive planning (Ackoff, 2001) and group model building (Vennix, 1999, Andersen et al., 1997, Vennix et al., 1992). The purpose of the techniques was to gain contextual specific knowledge of the project, through engaging what would be termed (in PNS) an extended peer community (Funtowicz and Ravetz, 1993).

Stakeholder knowledge is captured through all the workshop based sessions. There is however, a particular emphasis on stakeholder knowledge in techniques, such as the “opportunities vs. constraints” force field analysis based on the work of Lewin (1952). This is aimed at capturing stakeholder knowledge on what they consider the opportunities that can be exploited and also what might hinder a sustainable building from being developed from their perspective; additionally asking them to directly consider ideas on how to address some of the issues and outcomes of the process demonstrated that this did capture this knowledge.

Additionally, the relationships mapping exercise looking to build models of the different aspects that stakeholders had defined as important and the inter relationships between different requirements was also beneficial in integrating stakeholder knowledge and considering their perspectives on some of the relationships between requirements. In fact, this was captured by one group as an important aspect that should be considered immediately prior to the session see section 8.5.4 and Figure 8—14.

9.4 How this relates to Part 2 of the thesis

Part 1 was concerned with the feasibility of the development and testing of techniques to understand the values of the stakeholders and capturing these to inform the sustainability and value themes for the project. Keeney (1992) outlines that it is values that stakeholders are able to contribute to the decision making process and this section has provided a set of techniques for eliciting these values. It is also considered that these could be used to inform a project brief and the project specific sustainability and value themes. However, the stakeholders were also able to provide contextual knowledge on certain aspects, in relation to particular contextual issues that was important for the design team to understand. This aligns with PNS which integrates contextually informed insights of stakeholders with those of technical stakeholders. However, it aligns with traditional logic, which assumes that superior outcomes rest on the quality of facts informing them (Healy, 2011).

The next part of the thesis (Part 2) considers a decision making tool to select high value and sustainable roofs. It is intended that the themes emerging from engagement techniques as developed and trialled in Part 1 of the thesis will be useful in selecting the most appropriate context specific roof objectives. However, these would also require consideration as to how performance of different roof options would be measured against these attributes. Consideration is given to such attributes in Part 2 of the thesis, which explores the roof decision making framework and the information required to assign values to the performance of roof systems in order to inform decision making. Considering sustainability from a pragmatic realist perspective, sustainable roof selection would employ techniques and tools outlined in both Parts 1 and 2. Figure 9—4 shows the relationships between Part 1 and Part 2 of the thesis explicitly. The image shows blue arrows connecting these aspects.

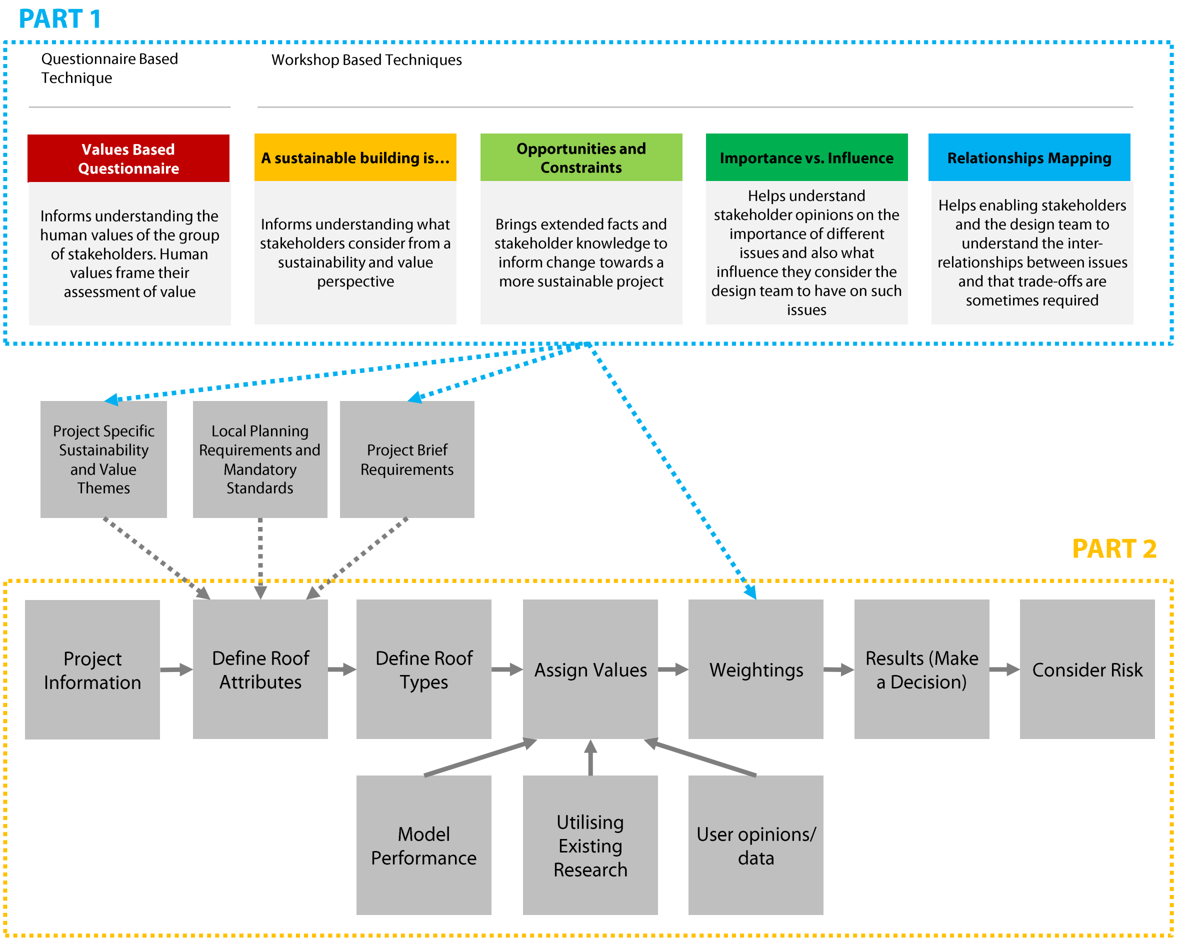


Figure 9—4 Relationships between Part 1 and Part 2 of the thesis

9.5 Conclusion

Section 9 has provided an overview of Part 1 of the research and discussed the engagement techniques developed to understand the stakeholder perspectives of sustainability and value in order to define the sustainability and value themes for a project. It discusses how the approaches address the research questions relating to Part 1 of the research and address areas identified as important through the literature. Feedback is also discussed. How the approaches developed through Part 1 of the research are related to Part 2 of the thesis is also briefly discussed.

Part 2 of the thesis is more concerned with the specifics of sustainable roof selection, which considers how quantitative information on the performance of roofs can help achieve project sustainability and value objectives.

Part 2: The development of an approach and prototype decision support tool (DST) to inform sustainable roof selection

10 Introduction to Part 2

This part of the thesis describes the development of an approach and an accompanying decision support tool (DST) to inform sustainable roof selection. It builds on earlier work presented in the previous section, which developed a set of stakeholder engagement techniques to define sustainability and value themes for a particular context. It is intended that the information from such techniques will be useful in informing the decision objectives. However, as Keeney (1992) states, "any decision requires a consideration of both values and facts on the performance of different options." This section aims to complement the normative approaches described in the previous section by providing the facts relating to decision objectives for the roof system. This section, therefore, focuses on understanding the performance of roofs in areas typically considered to represent sustainability on projects. It then develops a decision support tool to combine this data with the decision objectives to allow more informed decisions. This utilises Keeney's value focused thinking (VFT) as an overall structure and the simple multi-attribute rating technique (SMART) to integrate the roof performance information with the roof decision objectives, to rate the various roof options.

A literature review that considers sustainable roof selection is undertaken in Section 3, which provides a summary of research looking at the importance of the roof from a sustainability perspective. This provides the reader with the background and context to the problem. The research then looks historically at roof selection and details how the need has arisen for improved methods of selecting roofs to reflect current sustainability issues. The review then covers a variety of roof systems that will be considered in the approach to sustainable roof selection and accompanying DST and also considers the relationships of roofs to some commonly used environmental assessment methods. This literature review provides the basis for defining a set of roof attributes, which are typically considered from the literature in relation to sustainable roof selection.

Then previous work in the field of roof selection and decision making is reviewed. The objective of this is that the work undertaken in this thesis, builds on the knowledge gained through previous work and also bridges some of the gaps in knowledge. This was used to assess the current gaps in the literature and develop the research questions for this part of the thesis as detailed in Section 5.2 (question 2), which is as follows:

- Is it feasible to develop an approach and decision support tool to inform roof selection that:
    a. allows the rapid definition and assessment of different roof systems?

b. reflects the participatory nature of sustainability and allows for the consideration of stakeholder values?
c. incorporates context specific locally-relevant information from research on roof performance?

This section considers the above questions, through developing an approach and accompanying decision support tool to inform sustainable roof selection.

The following research objectives are considered, which can be linked back to the overarching research aim and related questions as shown in Figure 5—3:

- To define a set of attributes to assess roof performance
- To develop approaches to provide reliable, climate specific roof performance information to inform decision making
- To define a method which allows many different roof systems to be combined to consider the ‘roofscape’ of a project
- To develop an approach and decision support tool to aid in making more sustainable roof choices

These objectives are explored through the following sections of this thesis.

Section 11, provides context for this section of the thesis by considering the challenges of informing roof design and selection for a Middle Easter masterplan. This highlights some of the gaps in the research and the difficulties of taking approaches typically defined in one location and trying to use them in a different context. It provides a set of considerations for the rest of this section.

Sections 12 and 13, consider approaches to assessing the performance of a range of roof systems on particular attributes, which are discussed in the literature. This provides approaches to provide reliable, climate specific, roof performance information to inform decision making.

Section 14, then draws on the various strands of the research as a whole to develop an approach and decision support tool, to aid decision makers in making more sustainable roof choices.

Section 15, then discusses the various elements of Part 2 of the research and how they collectively address the research objectives.

11 Part 2: Action research Case Study 2A– The challenges of informing roof design and selection for a Middle Eastern masterplan

11.1 Introduction

This section considers the issues with informing sustainable roof selection on a real life project through an action research based case study. Whilst the literature demonstrated a number of challenges of the building design process with respect to the integration of sustainability in decision making, these were not significantly covered with respect to roof design. Therefore, this exploratory piece of action research was undertaken to consider the challenges of roof selection on a real world project.

This section draws heavily on a paper presented at the IWA international conference (Hampshire et al., 2012). This was written through reflection of trying to apply simple decision making techniques on an action research live case study project. It looks at the design process and the challenges of the sustainability consultant in order to define some of the challenges of informing sustainable roof selection on a real world design project.

The building industry is increasingly requiring rapid assessment of new technologies and systems. An emerging category of sustainability engineers and consultants are being asked to determine sustainable choices for the built environment, for a range of situations, from individual buildings up to masterplans for new cities. The timeframe to define and assess potential options is a matter of days or weeks, before reporting back to a client with a range of options, and typically a recommended course of action. This raises many problems, primarily how to assess new ‘sustainable’ technologies and systems. These challenges are identified, and through a case study example, resolutions are proposed and discussed before conclusions are made regarding decision making in this area.

In recent decades the drive for more robust decision making has led to an increasing amount of information being generated about sustainable design options, and the development of advanced simulation techniques. This has undoubtedly had a positive effect on the building industry, allowing detailed designs to be refined and optimised. Over a decade ago Cole (2000) stated “The research community has offered considerable knowledge on green buildings over the past couple of decades.” However, he goes on to comment that, “there are five areas which remain relatively uncharted (1) good robust information, (2) [going beyond] technological issues, (3) systems thinking and analysis, (4) understanding the process (5) good communication.” This is still considered the case today by the author working in industry

This section considers these areas, describing the role of the consultant, the context within which they work and the challenges they face when assessing sustainable design options. A short case study is then presented looking at how these challenges can be addressed early in the design process.

11.2 Background and context

The case study project is a multi-building, mixed use, urban development located in the Middle East in a sub-tropical arid climate. It is developer led, and therefore differs from case studies 1A, 1B, and 1C in that each of those case studies would be owner-occupiers of the building that were being developed. The project has been anonymised but is considered, by the researcher and colleagues in the sponsoring organisation, as typical of such type of development. At the concept stage, the project had numerous architects, consultants and engineers working in different offices around the world progressing the design. The client was a developer represented by a company based in the Middle East. The case study focuses on consideration of the roof options for the buildings from a client driven sustainability and value perspective.

11.3 Method

The following work is undertaken through an action research case study in the context described above. It represents how different approaches can be used to help inform decision making on a project. For each section of the case study, a brief description of what was carried out to address some of the above issues is given, followed by reflection on the process used. It should be noted that the researcher was established in the project team during the below example. The approach went through the following stages:

- Diagnosing
    - Literature review to identify gaps in the literature and potential techniques (see Section 3).
- Planning
    - Identification of the potential project on which to undertake the decision making approach
    - Simplification of the decision making approach due to the time frames of the project.
- Taking Action
    - Undertaking the decision making approach on the project
- Evaluating
    - Reflecting on the approach

- Suggesting areas of further work to be developed in rest of the thesis.

After an initial loop of action research, it became immediately apparent that the decision making approaches developed by Grant (2007), McCourt (2007) and Nelms et al. (2007) were not going to be able to be applied on this project, for the following reasons:

- The Middle Eastern context was significantly different to all the approaches.
- The approach of Grant (2007), was primarily focused on green roofs, whereas other roofs were being considered in the context of this work; additionally the six criteria defined by Grant (2007) were too limiting to consider. This echoed the feedback from interviews that she conducted with respect to her framework.
- With respect to McCourt (2007) again the criteria that were emerging as important, were very different to those identified by McCourt. Additionally, interviews with project managers were not going to be possible with respect to defining their requirements.
- With respect to Nelms et al. (2007) it was considered that the list of requirements, whilst comprehensive, was very abstract from the project and it would not be realistic to get a decision maker to go through over 60 criteria with respect to the roof choice. Additionally, it was not considered that the answers of North American individuals, abstract from the context, could be taken as representative of sustainability and value in the Middle East. Furthermore, due to the lack of performance data for roofs in the region, gaining data to convert into cost data was unrealistic. Additionally, putting a cost on things that were already very uncertain, was considered misleading by the researcher.

Therefore, to address some of the challenges previously outlined a simple four stage approach was used which involved; (1) Identification of roof related project requirements; (2) Prioritisation of requirements; (3) Comparison of the performance of options; and (4) Presentation of information. Each stage of the approach is described and reflected on in the context of the project.

11.3.1 Data sources

The data sources for the above information include a reflective account of the work kept by the researcher during the action research process. The researcher was central to the work, being a member of the project team within the sponsoring organisation. The researcher developed and reflected on the approach with other practitioners in the project team. The work was reviewed by several experienced professionals at regular intervals and also by the client team. Additionally, feedback was received from the client team stating that the approach was useful.

11.4 Results

The following sections discuss the output of the action based case study in relation to each step of the applied approach. Reflection is given in each case. The work forms the basis for the identification of a number of challenges that require addressing and compared to relevant literature.

11.4.1 Identification of requirements

The relevant roof related requirements were initially identified and captured for the development (see Figure 11—1). This was undertaken through a review of the project documentation by the researcher. This was considered necessary as the project requirements spanned several documents and consisted of hundreds of pages. In this form it was hard to see and work with the requirements for decisions relating to specific technologies and roof systems. Condensing this into a manageable form on which decisions could be framed was important and it meant that typical sustainability requirements, such as of energy, water, waste etc. could be assessed in line with wider project drivers.

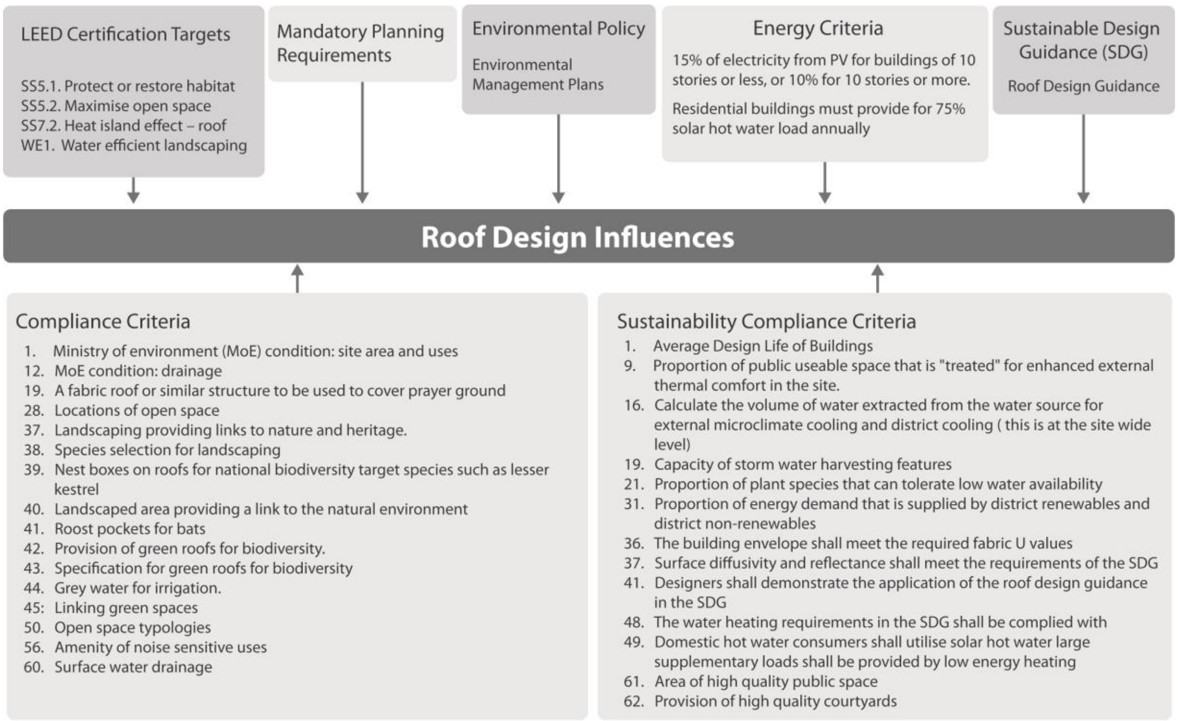


Figure 11—1 Roof related requirements and drivers

Reflection on the process

Keeney (1992) argues that ‘the standard way of thinking about decisions is backwards: people focus on first identifying alternatives rather than on articulating values’. In contrast, one may argue that a project’s requirements make the project and client’s values explicit. However, it is rare for project requirements to be prioritised in order of importance, and for them to be specific, measurable, achievable, realistic, and time bound. Therefore, further effort is required to transform them into a complete set of operational, preference independent and non-redundant objectives on which to base decision making (Keeney and Raiffa, 1976).

Going through such a process, whilst initially time consuming involving the review of several documents as detailed in Figure 11—1, offered a way of translating what can often be messy and unstructured early in the design process into a tangible set of criteria against which to make a decision with respect to roofs. This takes a more objective view of value where designs are tested against objectives which substitute for direct engagement with the customers (Thomson et al., 2003). Showing this explicitly with respect to criteria influenced by roof selection allowed the decision maker to understand what the consultant had defined as important to consider in the analysis and also link the options back to the wider strategic project objectives. Additionally, this allowed the importance of decisions related to different system choices to be highlighted. If the decision relating to a particular system or design, is likely to influence lots of requirements and objectives then it merits more attention than otherwise.

To consider the opinions of the stakeholder groups that may in the future occupy the project, it would have been ideal to engage them to understand the sustainability issues in more depth. However, as the project was of a significant scale, numerous large buildings with many elements of the design progressing at once and in a different country to the design team, along with uncertainty about who would eventually occupy the buildings, it was not feasible to engage potential stakeholders through either the questionnaire based or workshop based approaches outlined in Part 1. This identifies the importance of the project context in being able to apply techniques outlined in Part 1 of the research.

The roof related requirements for this project (as shown in Figure 11—1) were significantly different compared to the requirements used to assess the performance of roofs in Grant (2007), McCourt (2007) and Nelms et al. (2007). This demonstrates the need to establish the roof related requirements for the individual projects rather than stating a generic set of requirements for assessing the performance of roofs from a sustainability perspective. It tends to suggest that the requirements they identified are not generalisable and that a process is required to identify roof related requirements on a project by project basis.

11.4.2 Prioritisation

On the case study project it was unclear what the design team should focus on in the early design stages. This is not uncommon in projects. Through consultation with the client and architect it was eventually established that LEED was a priority. Other requirements that were also of high importance included a desire to generate a significant percentage of the project's energy from renewable technologies. These two aspects are complementary in many respects, meaning that achieving one helps the achievement of the other. However, where requirements are not complementary and trade-offs are required, prioritisation is important. This allows the design team to progress the design knowing which objectives are most important to achieve when it is not possible to 'have it all' given the project constraints. These constraints in the case of this project included the budget, the site and in this example case the roof area. The requirements for LEED credits and renewable energy generation had to be considered in parallel with other project requirements, which included utilising roof spaces as high quality communal areas to include pools and garden space. The roof area consisted of approximately 30,000m^2 of the 45,000m^2 plan area of the development. Therefore, in order to achieve many of the landscaping requirements, along with the desire to have open air pools and gardens, the roof space had a lot of competing interests. Requirements were never explicitly prioritised so the design team had to make assumptions on which ones were considered most important.

Reflection on the process

Prioritisation of what is most important to achieve is rarely done on projects. Clients' aspirations change over project lifetimes. Initially there is a tendency to 'want it all', but as budgets and time become pressured, holistic sustainability often becomes reduced to a handful of key features. But without understanding priorities, the designer is not informed as to what is important to progress through the design. Therefore requirements/targets should be prioritised in order of importance. This is highly important when considering sustainability and options which will inevitability involve trade-offs.

Ideally the process of prioritisation would be done through collaboration with the client to ensure that it would represent value from their perspective. However this was not possible due to the structure of the project team and lack of access to the client. Additionally it should be considered that access to the client can be difficult as the client is typically ‘multi-headed’ and represented by a team of people. This team was in another country and primary access may be through an architect. Feedback could take days or even weeks as discussions go through a chain of people. When decisions need to be made in a short time period to allow the design to progress, consultation with the client was impractical. Therefore the design team made their assumptions explicit on what they have prioritised.

After a significant period of time LEED was identified by the client team as a driver for commercial and marketing purposes. However, LEED was designed in the USA, primarily for use in the USA. Hence, design features may achieve LEED points even when they do not perform well in relation to the intent of the credit in the Middle East. This is due to the difficulties of measuring performance with respect to some aspects of design and the adoption of proxy measures. For example, with respect to urban heat island mitigation, green roofs are given a score based on the proportion of roofs that they cover, not on their performance in terms of mitigating the UHI. This shows an example of environmental assessment methods not reflecting their context of use. Additionally, there was little precedence of green roofs being used in the Middle East, so high uncertainty as to how they would perform.

11.4.3 Comparison

When considering roof technologies on the case study project a simple matrix was formed that allowed the design options to be compared in relation to the requirements (see Table 11—1). The performance of various systems could then be explicitly compared against them. This was done through expert understanding on qualitative issues alongside high level assumptions to inform simple rule of thumb models for aspects more easily quantified. Showing high level performance of numerous options in relation to the project requirements on one page was beneficial for the following reasons:

- It showed how the different options were likely to perform against a wide range of criteria on a simple scale, without the requirement to understand the different metrics required to quantify the performance.

- It showed the tradeoffs that were inherent in any technology selection. For example, solar PV and solar thermal performed well in terms of energy related requirements; however, they performed poorly when considering requirements relating to biodiversity (habitats), open space and urban heat island impact.
- Additionally, it showed where potential synergies may be achievable through combining different technologies and systems. For example combining solar PV or solar thermal with roof gardens may enable many requirements to be achieved simultaneously.
- Additionally, the sizing and location of different options was informed through undertaking an analysis of the solar radiation incident on each roof, and undertaking calculations based upon this.

Table 11—1 Comparison of options against requirements

	Requirement	**Desert roofs**	**Roof Gardens**	**High Albedo "Cool" Roofs**	**Solar PV**	**Solar Hot water**
LEED	SS5.1 Protect or restore habitat (1 point)	✓✓✓	✓✓✓	×	×	×
	SS5.2 Maximise open space (1 point)	✓✓✓	✓✓✓	×	×	×
	SS6.1 Stormwater design - quantity control (1 point)	✓✓✓	✓✓✓	×	×	×
	SS6.2 Stormwater design - quality control (1 point)	✓✓✓	✓✓✓	×	×	×
	SS7.2 Heat island effect - roof (1 point)	✓✓✓	✓✓✓	✓✓	×	×
	WE1 Water efficient landscaping (1 point)	✓✓✓	✓✓✓	×	×	×
	EA2 On-site renewable energy (4 points)	×	×	×	✓✓✓	✓✓✓
Compliance Criteria	Drainage - storm water runoff generated within the project to be collected through a positive drainage system and discharged to the public sewer network	✓	✓✓✓	×	×	×
	A fabric roof or similar structure to be used to cover prayer ground…	N/A	N/A	✓✓	✓	N/A
	Location of open space	✓	✓✓✓	×	×	×
	Landscaping – providing links to nature and heritage	✓	✓✓	×	×	×
	Species selection for landscaping: Landscaping – providing links to nature and heritage	✓✓✓	✓✓✓	×	×	×
	Nest boxes on roofs for national biodiversity target species, such as lesser kestrel	✓	×	×	×	×
	Landscaped area providing a link to the natural environment	✓	✓	×	×	×
	Roost pockets for bats	**?**	**?**	×	×	×
	Provision of green **roofs** for biodiversity	✓	✓	×	×	×
	Specification of green **roofs** for biodiversity	✓	✓	×	×	×

Reflections on the process

At this early stage, simple rule of thumb modeling was done to assess performance of easily quantified aspects such as energy from Solar PV. Whilst fine for some aspects of performance, quantifying factors such as the thermal, and hydrological performance of green roofs was extremely difficult. Therefore, an improved way of assessing performance would have been beneficial. Additionally, the rules of thumb used in previous roof decision making tools (Grant 2007, McCourt 2007, Nelms 2007) with respect to the performance on many of the above attributes were not considered appropriate for use in the Middle East in the climate type of the project as such techniques had typically been used in a significantly different climatic context. Additionally, building various options and modelling them could not be done fast enough to test numerous options out quickly. Therefore, the performance of different options had to be assessed qualitatively.

This was frustrating as there was significant amounts of research available on the performance of green roofs in different climates, but the research is typically not categorised in a way which can be found and accessed quickly depending on the project context. Therefore, this is out of reach of the design consultant. It is considered that a way of categorising the green roof research, would speed up this process and make the research that has been undertaken in the performance of roof systems more accessible.

With respect to softer objectives, scores had to be based upon the consultant's own understanding and knowledge. Such scoring can be prone to biases. This raises questions with how to militate against these biases? Whilst on the project, the scoring was reviewed by another consultant to assess that it seemed feasible. Future work could consider ways of getting a number of informed experts to score the options based on their knowledge, in order to understand the variation and level of disagreement. Group pressures can be avoided by eliciting these judgments anonymously and independently (Surowiecki, 2005) and future work could usefully explore the role of techniques such as the Delphi method, which can be useful in guiding these judgments to a consensus (Rowe and Wright, 1999).

Sustainable technologies or design solutions often perform a multitude of services, although they may not be the best provider of any single service. For example, green roofs do not perform the best in terms of mitigating the urban heat island effect, reducing heat transfer into rooms below, or reducing runoff. Each of these things individually can be done better by other systems or technologies; reducing heat transfer can be done more cheaply by insulation; reducing runoff can be better quantified and captured through rainwater harvesting; and urban heat island effect better mitigated through highly reflective surfaces. However, none of these other systems in isolation can do the multitude of things that a green roof can. Additionally, these options do not offer the other benefits of green roofs that may be considered of value. For example, the green roof could offer external garden space with good views, increase biodiversity, improve acoustics and aesthetics of an otherwise bland space. These are issues that are much harder to quantify/model, but may be considered of much more importance to the client. By holistically considering options through the decision making it might be that the client can see the value of certain sustainable design options. In these circumstances, the sustainable option has a much greater chance of making it onto the project.

This is not an uncommon problem with respect to decisions involving multiple objectives. Such decisions often involve lots of information that requires handling simultaneously. Without a system to support the decision, the decision maker is forced to use simple mental strategies or heuristics in order to make a choice, unless there is a system in place to support their decision. For example, unaided decision makers often have difficulty in making tradeoffs between objectives as they tend to use non-compensatory strategies so that the relatively poor performance of an option on one objective is not compensated by its good performance on other objectives (Goodwin and Wright, 2009). Simple comparison systems can help in such situations.

Whilst it is accepted that weighting and normalising the scores can be beneficial this was not done on the case study project. The reason was that this would have required a greater investment of time in the initial project stages, and the author believes that it would not have brought a much deeper insight to allow decisions to be better informed. This was primarily due to the lack of performance information with respect to the performance of some options against some attributes which could not be gathered at this project stage for the context in question. Techniques such as multi-criteria decision analysis (MCDA), which attempt to weight the performance options against attributes, can play an important role in decision making. However, due to limited access with the client and the fast paced nature of the project, the consultant would have had to input their own weightings to represent importance of different objectives. Additionally, without improved information, weighted performance based on what the consultant considered to be important may have been misleading. Decision making should allow mutual learning to take place and put the decision maker in a more informed position, rather than simply giving a number which represents what the consultant considers to be the best option, based on the consultants own weightings and scores on information with high uncertainty (Keeney, 1982, Goodwin and Wright, 2009). Therefore, weighting was decided against in this context. However, with improved information on the performance of options, it is considered that a structure for combining technical performance information with qualitative opinion on what was important would be a worth-while future development. This aligns with the work Schade et al. (2011), who argue that sustainability decisions are required early in the process and the work of Kaatz, Root et al. (2005), who argue that formal decision making processes are required.

11.4.4 Presentation of the information

In the project context the consultant’s role is often to inform the decision making, but not actually make the decision. This means presenting the client with clear information on which they can make their own decision. From a consultant’s perspective it is important to inform the design, through showing what different options may involve to the different disciplines. For example, what does the architect need to consider when progressing the design? This was done on the case study project through detailing the areas of different technologies required for the roofs to meet a range of requirements and maximise the value of the roof space (see Figure 11—2). This then allowed the architect the freedom to be able to use their skills to do this in an aesthetically pleasing way and integrate with other building systems.

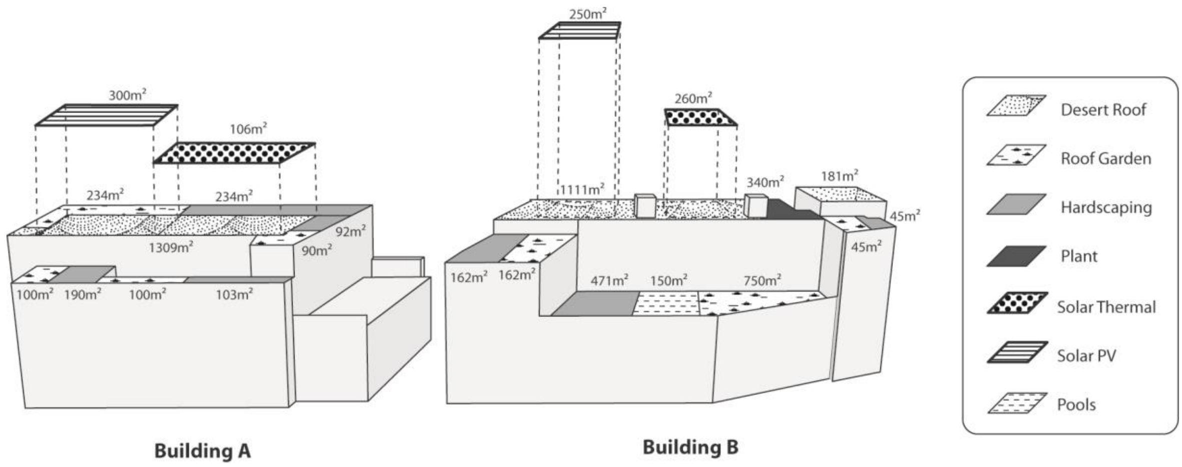


Figure 11—2 Example layouts of roof areas for presentation to client

Reflections on the process

This simple and visual approach was received well by the Client and the wider design team as it informed what combining different systems would mean in terms of the design in this context. It also became something around which dialogue could be based. Also in the case of many disciplines, it was not necessarily important for them to understand the technical performance of different roof systems, but only how it impacted on their area of work i.e. the areas that needed to be incorporated and where the technologies should be placed to perform optimally. This simplification was therefore advantageous and proved to be at an appropriate level of abstraction to communicate to a wide range of stakeholders. Further information was supplied regarding what the build-up of each roof type meant to different disciplines and informed by the use of the framework outlined by Nelms et al. (2005, 2007), which provided a useful guide as to the relationships with other systems.

11.5 Discussion

In an idealised world, the design consultant would be presented with clear criteria upon which to base system choices; have complete information regarding the performance of all the options over their lifecycle; have enough time to be able to scrutinise this information and make well-grounded recommendations with minimal amount of uncertainty and risk. Unfortunately, the action research demonstrated that the environment of the design consultant is typically pressured, with little time, project feel or information on which to base decisions. Additionally, decisions with respect to sustainability often require integration with other building systems which, if not decided upon and designed in from the early project stages, will be too costly to incorporate at a later date.

The work presented in this section represents a sustainability consultant's attempt to support decision making on a complex project, with a high degree of uncertainty and under significant time constraints. It provides a starting point for this research. It outlines the key issues as considered by the researcher in trying to inform more sustainable decision making with respect to roofs.

It is considered that whilst the work contained some simplifications of more academic methods, the decision making frameworks presented were useful under the circumstances as detailed by comments from the Client Review and also fellow practitioners, however significant improvements could be made. Many of the pressures are generic across projects, like a desire to make decisions quickly under uncertainty. The following headings describe the key difficulties with informing roof selection on a live building project.

11.5.1 The role of the sustainability engineer/ consultant

The role of the consultant is typically to support and inform, but not make decisions. This can be challenging as the situation and problems that they are aiming to help resolve are typically messy and unstructured. These problems are characterised by the existence of multiple actors with multiple perspectives, incommensurable and/or conflicting interests, important intangibles and key uncertainties (Mingers and Rosenhead, 2004). To resolve these issues, consultants also have to relate the performance of different systems back to criteria that the client considers important, and at an appropriate level of abstraction.

11.5.2 Combination of roof types

A limitation of the comparison of the options demonstrated above was that this compared discrete roof systems. As can be seen from the section, "presenting the information", the final designs involved a combinations of roofs designed to meet numerous requirements. Therefore the choice was in this case not between several discrete roof systems, but rather between several roofscapes built up of numerous different roof systems. Therefore, a way of being able to rapidly create several different roofscapes with a combination of roof systems and a way of assessing their performance is required in order to select between combinations of different roof system types. This is not considered in the existing literature with respect to roof selection.

11.5.3 Quantifying the performance of roof options

To justify the selection of green roofs, architects, engineers and clients require quantitative data, in addition to the widely available qualitative information on green roof benefits, to inform decisions early in the design process. From the literature review on the performance of green roofs it is clear that qualitative and quantitative information on the performance of green roofs is abundant (see Section 3.6 and for more detail Appendix L, Appendix M and Appendix O). What is not abundant is quantitative information that is context specific with respect to climate of the site and the roof build-up. For consultancies designing buildings in numerous countries with significantly different climates, collating this information for individual projects can be problematic. This is due to the fragmented nature of the information available along with much of the data being case specific. The pressured project timeframes in industry do not allow practitioners the time to search through and access the required information, or draw inferences from case study data to make informed decisions. Additionally, it is often not clear if there is any green roof guidance for the region in question. Therefore, a method of identifying the most relevant peer reviewed journal papers with respect to elements of roof performance would be beneficial in getting more credible performance information. Such a method could include categorising disparate information from numerous data sources. This provides an area of further work which is addressed in Section 12.

The quantification of the performance of roof options was difficult within the time constraints of the project. Whilst the performance of various systems and their interaction with the building can be modeled through building simulation programs for some aspects of performance (Sailor 2008), conducting simulations at an early project stage on a number of design options is not typically feasible due to the time restraints and the required data inputs being uncertain and in flux. This is typically only possible with more complete information when refining and optimising designs at the later stages of the design process.

Whilst some have undertaken modelling of various roof options (Scherba et al., 2011), this is generally done for a single parameter (e.g. heat flux from roof), for a small range of roof options. There is a current gap in the research with respect to a standardised method to obtain improved performance data, early in the design process to provide a quantitative assessment of the performance of numerous roof options. The performance of different roof systems is context specific and thus a method of being able to model a range of roof options for a particular site would be very beneficial in gaining more reliable context specific information when it has the most influence in the design process. Approaches to being able to model performance for different contexts are beneficial and considering how this information can feed into decision making would be beneficial. This is as an area of further work which is considered in Section 13.

11.5.4 Proving the value of sustainable choices

The financial payback of many sustainable design options is often long, and this information is unlikely to justify the inclusion of more sustainable technologies, unless enforced through regulations or policy. This can leave designers frustrated as designs considered to improve environmental and social sustainability are often discounted as they are considered by the client to not offer value. Paradoxically, this makes such options unsustainable as they have not sustained their existence past the design stage.

Therefore it is important to get a holistic picture of what a client/stakeholder group values for the project, and justify roof design options in these terms, not just aspects which are easily quantifiable such as cost, energy, carbon and water use. This is something that is not possible through solely quantitative techniques. Ideally this would involve close collaboration with the project stakeholders, alongside analysis and prioritisation of their requirements.

Many of the available tools and techniques tend towards quantitative, rational, ‘hard’ scientific approaches – for example computer simulated models, which try to capture the complexity of the multi-modal interactions. These struggle to incorporate the softer, value led elements of sustainability. Therefore, a question arises as to how such techniques can be integrated with other softer approaches at understanding value, to inform decisions early in the design process when consideration of options from a sustainability perspective is required.

A set of approaches for doing understanding what is important from the perspective of the stakeholders through exploring their values and what they consider to be important from a sustainability perspective is covered in depth in Part 1 of this thesis. An approach which can bring together the values of the stakeholders with the quantitative performance data would allow value to be demonstrated in relation to what clients think is important from a sustainability perspective.

11.5.5 The limitations of environmental assessment methods

Building Environmental Assessment Methods (EAMs), such as LEED and BREEAM have grown in popularity over the past decade. EAMs consist of a number of criteria on which to assess the environmental performance of buildings. These criteria have been defined and then weighted in terms of importance by a group of experts and industry professionals, often for a particular building type and climate. They have received much attention across the industry, as they offer a scoring system on which to judge the environmental performance of buildings (see Section 2.3.1 for more information).

EAMs have undoubtedly had a positive impact, as they have brought environmental issues to the forefront of design. They also offer a framework which can be used to inform design. However, recently EAMs have started to be used outside their original scope in new contexts and removed from their countries of origin. In such situations, when EAMs become drivers of design, they can have a significant negative impact, as the way of assessing performance can reward options which may not represent the intent of the credits within the system. For example, utilising LEED (developed for the USA) in the Middle East can reward design options that are not environmentally beneficial in that context. Additionally, EAMs do not generally address wider sustainability considerations such as social or economic aspects. For example, green roofs on the Middle Eastern action research case study scored very well in relation to the criteria outlined in LEED, even though they may not survive due to harsh conditions. Additionally, they are likely to require significant amounts of water. They are also unlikely to perform as well as cool roofs in terms of mitigating the urban heat island effect but would achieve the respective credit in LEED through the application of a smaller area of green roof compared to white roof. This demonstrates on the project, some of the issues outlined with applying the techniques out of the context which they were designed and the importance of the criteria used to assess performance.

11.5.6 Biases in qualitative scoring

Additionally, with a qualitative scoring method, there is likely to be bias in the scoring. Further work in the next section considers ways in which performance can be assessed quantitatively where possible and where this is not possible, techniques can be used which allow design consultants to be able to feed in their opinions on which system will perform best in a more robust and accountable manner.

11.6 Further work

The challenges identified through the action research case study have informed the below considerations that need to be addressed through the development of an approach to inform sustainable roof selection and reinforced some of the gaps in the literature. These provide a robust basis for the further development of decision support tools:

- The development of processes that can be used to define the sustainability aspirations of the project from the perspective of the project stakeholders. The lack of priorities shown in the briefing documents demonstrate some of the issues of not engaging stakeholders in the design process. This is extensively considered through Part 1 of this thesis.
- The incorporation of techniques to remove biases in scoring.
- The development of a set of metrics / decision objectives that could be used to assess the performance of different roof options with respect to sustainability.
- The development of a process that helps identify the most suitable roof performance information for a project’s context?
- The development of methods of undertaking modelling quickly, at the concept stage, to understand the performance of options at the earliest possible design stages are required.
- The development of an approach to the application of weightings to represent the importance of achieving different criteria considered important with respect to roof selection for the project.
- A way of understanding risk/uncertainty of certain options and the sensitivity of the decisions to changing weightings and the uncertainty in the performance of the various systems.

The following sections of this part of the thesis address the above points.

11.7 Conclusion

This section has applied an action research methodology to understanding the challenges of roof selection on a real building project in the Middle East. It outlined a method for application and provides a reflective account of the application of the method, before then discussing some of the challenges of roof selection. Further work is then proposed and provides some requirements for the development of an approach to roof selection.

The next section considers one of the challenges identified in relation to the quantification of the performance of roofs, and helps define a process to identify the more suitable roof performance information for a project's context.

12 Part 2: Development of an approach to utilising existing research

12.1 Introduction

This section considers how to address one of the limitations of earlier work and gaps in the literature with respect to being able to rapidly find and utilise the most context specific and relevant roof information. It is addressing aspects of research questions, *"How can reliable information with respect to the performance of roofs be brought together at the earliest stages in the design process to inform sustainable roof selection?"* In answering this question, it is addressing challenges of the design process with respect to being able to identify the most suitable roof performance information for a project's context.

This section builds on the work presented in Hampshire et al. (2011). Research on the performance of green roofs has advanced rapidly over recent years with much research documenting their diverse benefits, which include improvements in roof lifespan and whole life costs (Wong et al., 2003c), biodiversity (Brenneisen, 2006, Dunnett et al., 2008b), visual amenity (White and Gatersleben, 2011, Yuen and Nyuk Hien, 2005); noise reduction (Van Renterghem and Botteldooren, 2008, Van Renterghem and Botteldooren, 2009) and thermal and water retention performance. With the growth in green roof research there is now a significant amount of quantifiable data. This could potentially be used to justify the inclusion of green roofs on projects. However, much of this data is case specific, derived from field experiments in a certain climate for a specific green roof system. This means that generalising the data for use in different circumstances is difficult. Additionally, establishing whether the research data is appropriate for use in different situations often requires time consuming, resource intensive investigation. Unfortunately, this limits the usefulness of the research to practitioners.

To make the research accessible and useful for the design, selection and justification of green roofs, some structure is required to assess which green roof data is appropriate for the project's context. This was identified through the action research case study project as detailed in Section 11. In order to be able to transfer the conclusions and results of one study to a new design, it is essential that the climates are similar and the green roof types are also similar. Therefore, the aims of the research are; (1) to categorise thermal performance and hydrologic performance of green roofs with respect to climate and roof type; (2) to develop a method to use the categorisation as a decision aid and; (3) to highlight regions and climates with little research on the performance of green roofs.

The focus is to develop a process to select the most relevant papers and consider their output to inform the performance requirements in the decision making process. The chosen parameters are in relation to thermal and hydrological performance. These parameters were selected as they are highly interrelated and depend on similar attributes. These include; climate, substrate depth, vegetation type and density (Getter et al., 2007, Czemiel Berndtsson, 2010, Sailor, 2008). Additionally, there has been significant research in the thermal and water attenuation performance of green roofs, meaning that a method of handling the data will be beneficial. Furthermore, these aspects are perceived as being particularly important by many authors.

Kohler et al. (2002) state *"that the most obvious argument for green roofs is the reduction of surface temperatures".* Other authors note the importance of quantifiable data on attenuation performance stating that if *"green roof installations are to become commonplace in the United States, quantifiable data that document the ability of green roofs to retain stormwater under the climatic conditions of the region must be available"* (VanWoert et al., 2005). Many authors have also emphasised the role of climate in the performance of planted roofs (Theodosiou, 2003, Sailor, 2008, Schroll et al., 2011, Stovin, 2010). Other key variables include growing media depth, irrigation and vegetation type and density (Sailor, 2008, Dunnett et al., 2008a).

Review articles on both the thermal performance (Castleton, Stovin *et al.*, 2010) and hydrological performance (Czemiel Berndtsson, 2010, Mentens et al., 2006, Rowe, 2010) have been published. This section seeks to map both types of research with respect to climatic conditions and in relation to their key variables. In doing so it seeks to provide a decision support aid to help practitioners establish which research is most appropriate to inform their decision making. The decision aid is made up of the following parts; a map of the currently available research, categorised according to climate type; summary tables outlining the key research findings of existing research and; a flow chart demonstrating how these two parts of the decision support tool can be used to aid in design and selection decisions.

12.2 Method

The method primarily involved undertaking a meta-analysis of secondary data from the literature. An updated version of the widely used Koppen-Geiger Climate Map was used to categorise the research according to climate type (Peel et al., 2007). The maps were originally based upon the vegetation distribution for the various areas and thus are considered particularly appropriate for categorising the performance of vegetated roofs. Classifying the research according to climate type allows the results of field experiments to be generalised to projects in similar climates with similar green roof build-ups. Whilst the author appreciates that there can be local variations within the climate classification, it is considered that this will provide an improved initial indication of whether the data is transferable in the early stages of a project when information is limited.

To ensure that papers have been peer reviewed and to maximise scientific credibility, reference has only been made to journal papers. Whilst it is appreciated that research has been undertaken in many languages, the papers reviewed are all written in English. Further reviews such as Mentens *et al.* (2006) that summarise in English the runoff retention research from journal papers written in German would potentially be very useful for practitioners and researchers.

The research assessed includes; field experiments (FE) (experiments exposed to the external environment); controlled laboratory experiments (LE); computational and mathematical modelling (M); and literature reviews (LR).

In addition to the research being plotted on the maps, the main findings for each piece of research are summarised in tables. Main factors, such as green roof build-up (extensive/intensive), season of research, and findings are included and were selected based upon previous research, which highlighted these as key factors affecting their performance (Czemiel Berndtsson, 2010). In terms of roof build-up, “extensive” is defined, for the purposes of this paper, as roofs with less than 150mm of substrate and, “intensive” as having more than 150mm depth of substrate. The data tables are included in Appendix Q .

A simple flow chart is proposed in Figure 12—1, along with two examples to demonstrate the process by which the map (Figure 12—2) and summary tables Table 12—1 and Table 12—2 can be used in parallel to help inform green roof selection, by establishing which research is most appropriate.

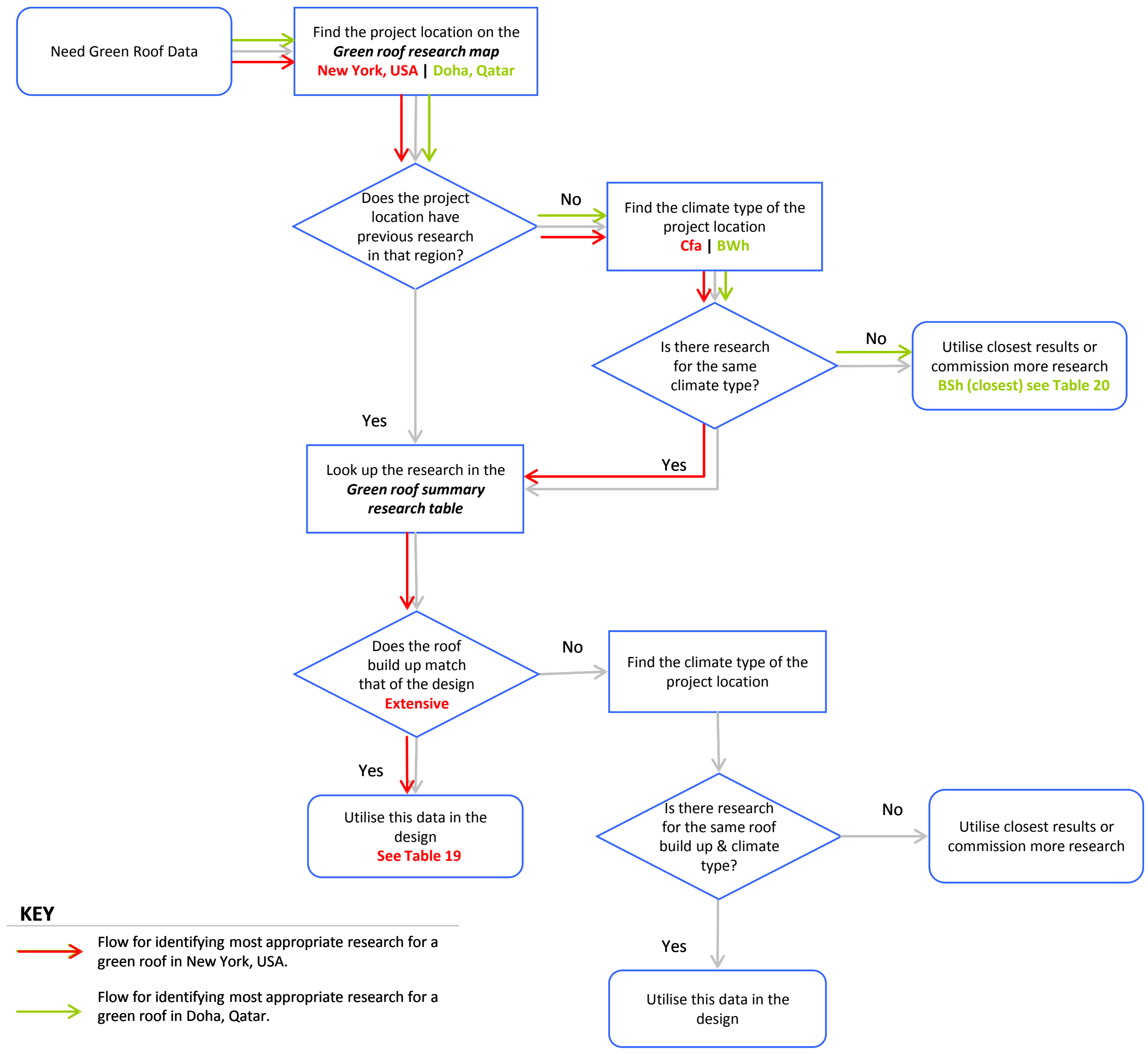


Figure 12—1 The simple flow chart detailing how to utilise the green roof research map (Figure 12—2) and the research summary tables

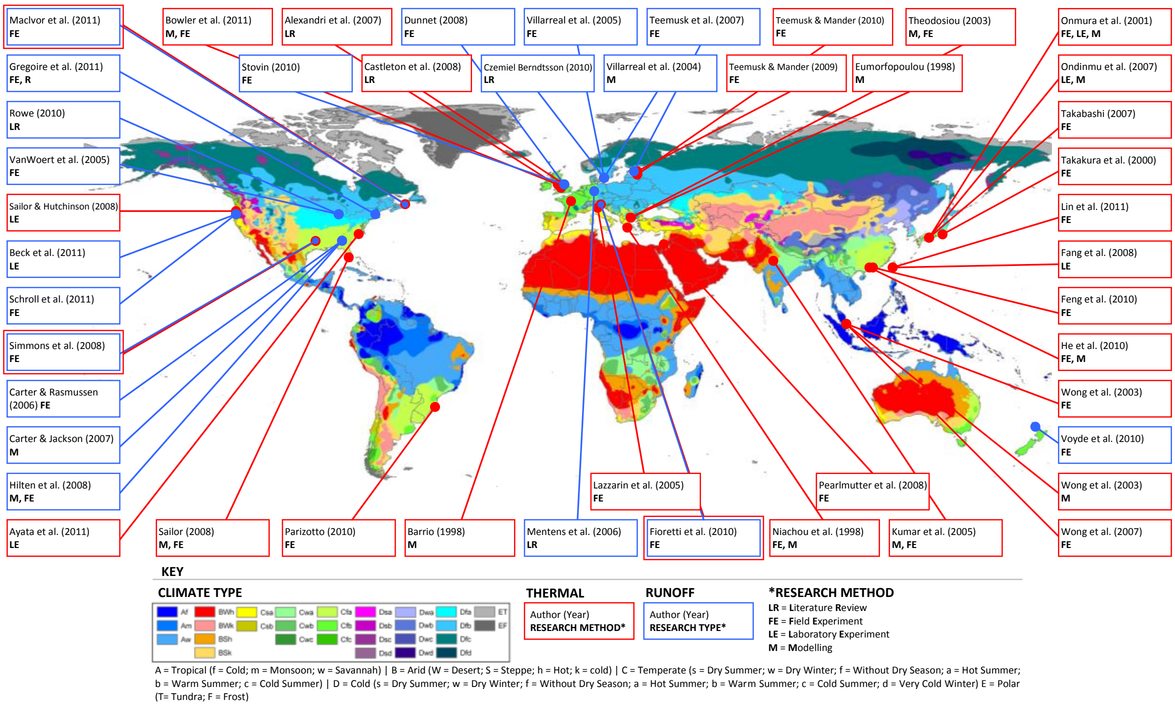


Figure 12—2 The green roof research map, showing the location of thermal and hydrological green roof research plotted on the updated Koppen Geiger climate classification (Peel et al., 2007)

12.3 Results

For a project with an extensive roof located in New York, the red annotations in Figure 12—1 outline the process that would be followed through the flow chart. The green annotations represent the flow for selecting the most appropriate information for Doha, Qatar.

Table 12—1 and Table 12—2 outline the results that would be returned for New York and Doha respectively. This data can then be used to inform decision making. Additionally, the tool is hierarchical in nature allowing the user the ability to see more in depth information where necessary in particular areas. For example, whilst, “intensive” / “extensive” may be an appropriate initial indication of the roof build-up, the importance of substrate type and plants is also extensively documented. Therefore, if the user of the decision support tool wishes to find more information on the roof build-up they can simply click on this and get further detail as demonstrated in Appendix S. This also demonstrates the differences in what appears at first glance to be very similar roof build-ups. Thus this level of information is important when assessing the performance in more depth.

Table 12—1 Example results that may be applicable to the design and selection of a green roof in New York, USA.

Reference	Research Type[1]	Method[2]	Study Location	Climate Type	Season	Substrate Depth	Main findings
Carter & Jackson (2007)	**SWR**	**M, FE**	Athens, Georgia, USA	Cfa	Annual	Extensive (76mm)	Hydrologic modelling demonstrated that widespread green roof implementation can significantly reduce peak runoff rates, particularly for small storm events.
Carter & Rasmussen (2006)	**SWR**	**FE**	Athens, Georgia, USA	Cfa	Annual	Extensive (76mm)	Green roof precipitation retention decreased with precipitation depth; ranging from just under 90 percent for small storms (<2.54 cm) to slightly less than 50 percent for larger storms (>7.62 cm). Average runoff lag times increased from 17.0 minutes for the black roof to 34.9 minutes for the green roof, an average increase of 17.9 minutes. Precipitation and runoff data were used to estimate the green roof curve number, CN = 86.
Feng & Meng, *et al* (2010)	**T**	**M, FE**	Guangzhou, China	Cfa	Jul (11 days)	Extensive (40mm)	Experimental results demonstrated that within 24 h of a typical summer day, when soil was rich in water content, solar radiation accounted for 99.1% of the total heat gain of a Sedum Lineare green roof while convection made up 0.9%. Of all dissipated heat 58.4% was by the evapotranspiration of the plants–soil system, 30.9% by the net long-wave radiative exchange between the canopy and the atmosphere, and 9.5% by the net photosynthesis of plants. Only 1.2% was stored by plants and soil, or transferred into the room beneath.
Hilten & Lawrence, *et al.* (2008)	**SWR**	**M, FE**	Athens, Georgia, USA	Cfa	Jan - Aug	Extensive (100mm)	The study revealed that rainfall depth per storm strongly influences the performance of green roofs for storm water mitigation, providing complete retention of small storms (<2.54 cm) and detention for larger storms, assuming the measured average moisture content (10%) as the antecedent condition.
Onmura & Matsumoto, *et al.* (2001)	**T**	**FE, M, LE**	Osaka, Japan	Cfa	Aug (23 days)	Extensive (30mm)	The roof surface temperature decreased from about 60 to 30°C during the day time, which was estimated to be followed by a 50% reduction in heat flux into the room by simple calculations.
Parizotto & Lamberts (2010)	**T**	**FE**	Florianópolis, Brazil	Cfa	Mar (7 days) & May (7 days)	Extensive (140mm)	During the warm period, the green roof reduced heat gain by 92 to 97% in comparison to ceramic and metallic roofs, respectively, and enhanced the heat loss to 49 and 20%. During the cold period, the green roof reduced heat gain by 70 and 84%, and reduced the heat loss by 44 and 52% in comparison to ceramic and metallic roofs, respectively.
Simmons & Gardiner, et al. (2008)	**SWR, T**	**FE**	Austin, Texas, USA	Cfa	Oct - Nov & Mar - Jun	Extensive (100mm)	Preliminary hydrologic and thermal profile data indicated not only differences between green and non-vegetated roofs, but also among green roof designs. Maximum green roof temperatures were cooler than conventional roofs by 38°C at the roof membrane and 18°C inside air temperature, with little variation among green roofs. Maximum run-off retention was 88% and 44% for medium and large rain events but some green roof types showed very limited retention characteristics.
Takakura & Kitade, *et al.* (2000)	**T**	**FE, M**	Tokyo, Japan	Cfa	Summer (3 days)	Extensive (140mm)	LAI up to 3 can significantly increase the cooling effect on the air space. A simulation model was developed, and the effect of evapotranspiration was taken into account. The simulated results agreed fairly well with measured values when evapotranspiration was not large, but there was some difference at high evapotranspiration rates.
Takebayashi, & Moriyama (2007)	**T**	**FE**	Kobe, Japan	Cfa	Aug & Nov.	Intensive (210mm)	In the daytime, the temperature of the cement concrete surface, the surface with highly reflective grey paint, bare soil surface, green surface and the surface with highly reflective white paint are observed to be in descending order.

[1] SWR = Storm Water Retention; T = Thermal | [2] M = Modelling; FE = Field Experiment; LE = Lab Experiment

Table 12—1 shows the results for climates that are similar New York's according to Koppen-Geiger climate classification (Cfa). Some of the results will be more relevant than others. However, this provides an initial indication of the research and possible thermal and rain water retention benefits. As no results were available for Doha's climate type (BWh), the closest climate type (BSh) was selected as the most appropriate and the results are shown in Table 12—2. However, these results should be used with a greater degree of caution.

Table 12—2 Example results table for green roof research that may be applicable to the design and selection of a green roof in Doha, Qatar

Reference	Research Type[1]	Method [2]	Study Location	Climate Type	Season	Substrate Depth	Main findings
Kumar & Kaushik (2005)	T	**M, FE**	Yamuna Nagar, India	Bsh	Jun	Unclear	The model is found to be very accurate in predicting green canopy-air temperature and indoor-air temperature variations (error range 73.3%, 76.1%, respectively). Cooling potential of green roof is found adequate (3.02kWh per day for LAI of 4.5) to maintain an average room air temperature of 25.7 1C. The present model can be easily coupled to different greenhouse and building simulation codes.
Niachou & Papakonstantinou, *et al.* (2001)	T	**FE, M**	Athens, Greece	Bsh	Jun - Aug	Unclear	During a typical summer day lower indoor air temperature is measured in the building with the green roof, with dense samples of measurements not exceeding the value of 30°C, in periods where the air conditioning systems were not operating. On the contrary, in the building without the green roof, the air temperature was exceeding a 30°C value and the daily temperature width was also higher. In the case of the non-insulated roofs with and without the green roof, the estimated differences of the heat transfer coefficient varied from 6 - 16W/m^{2}K. Finally for well-insulated roofs the differences of the heat transfer coefficients are much lower ranging from 0.02 to 0.06 W/m^{2}K. As a results the heat insulation performance of the green roof becomes considerable in constructions with low or no insulation.
Pearlmutter & Rosenfeld (2008)	T	**FE**	Be'er Sheva, Negev, Israel	Bsh	Summer	Intensive (160mm)	Covering a building's roof with soil, wetting the soil and shading the wet soil surface may provide a simple and efficient means of low-energy cooling in hot and dry climates – has been largely confirmed under the conditions of the experiment.
Santamouris, & Pavlou *et al.*(2007)	T	**FE, M**	Athens, Greece	Bsh	Sep - Dec	Unclear	The energy performance evaluation showed a significant reduction of the building's cooling load during summer. This reduction varied for the whole building in the range of 6–49% and for its last floor in the range of 12–87%. Moreover, the influence of the green roof system in the building's heating load was found insignificant, and this can be regarded a great advantage of the system as any interference in the building shell for the reduction of cooling load leads usually to the increase of its heating load.

[1] SWR = Storm Water Retention; T = Thermal | [2] M = Modelling; FE = Field Experiment; LE = Lab Experiment

12.4 Discussion

The above examples show how the map and the decision support tool can be used to reference data for decision making and design. Current trends suggest that research data will increase with time and thus more climate types and roof types and regions will have data on their various benefits. The following discussion is based around the third aim of the paper; *to highlight regions and climates with little research*. It is appreciated that the review is not fully comprehensive due to some articles not being accessible. Additionally, the focus has been primarily on green roof literature however, literature from other fields, such as Bowler, Buyung-Ali *et al's* (2010) review of urban greening literature may also be beneficial in justifying design decisions.

Table 12—3 Reviewed green roof research by broad climate type and research type.

Research type	Climate type					Research method			
	A	**B**	**C**	**D**	**E**	**M**	**FE**	**LE**	**LR**
SWR	0	0	9	7	0	3	17	2	2
T	4	4	13	3	0	18	26	4	4
Totals	4	4	22	10	0	21	43	6	6

As can be seen from the research map (Figure 12—2) and Table 12—3 there appears to be significant research with regards to the water retention benefits of green roofs occurring in Europe, and the USA, in predominantly temperate *C type* climates. Additionally, research has recently been undertaken in cold climates for both storm water retention and thermal performance. Unfortunately, tropical and arid climates have not received much attention in relation to storm water retention. The lack of data regarding runoff benefits is probably less relevant for arid climates, as they are generally dry. However, information regarding watering requirements would be beneficial. Whilst some thermal data is available for tropical regions further clarification would be beneficial, as Kohler *et al.* (2002) suggest that the potential of green roofs in these regions is large. Whilst none of the reviewed papers discussed performance in the Polar Regions, limited development occurs in these areas and thus immediate focus should be on their performance in more populated areas.

Significant research has been undertaken on extensive roof types. Research looking at more intensive green roofs would be beneficial. Unfortunately, many of the descriptions of the roof build-ups in the literature are vague, which limits their usefulness when trying to utilise the results to inform roof design and selection. For example in Table 12—2, three of the four papers referenced as applicable to that particular climate have unclear information regarding substrate depth. This means that designers are unsure as to what the performance of the different roofs tested refers to and cannot consider how the results potentially relate to their design.

Field experiments are the primary research type for the reviewed thermal and water retention research. It is hoped that the decision support tool will help practitioners identify relevant research more easily. The second most popular research type is modelling. Modelling is often conducted and validated in line with field experiments. Many of these models show high correlation with the results of their own field experiments. However, these models are not in widespread use across the industry as they are not often compatible with building simulation programs. Additionally, it would be beneficial to try the models using data from different climates types to test and document their generalisability.

An emergent finding from this categorisation exercise, is that the majority of papers focus on very small niche areas of consideration. Few studies look beyond just one element of performance and less still focus on elements of decision making. Additionally, very few published studies look at the difficulties of selecting between different roof systems. A study by Simmons et al. (2008) also tried to replicate studies across different sites and showed that green roofs do not perform equally. This is because performance varies depending on the design, the materials selected, the planting types and the climate, and many other variables. The performance of green roofs is dependent on so many parameters that it’s accurate modelling is difficult. These parameters are listed in the most sophisticated model currently developed for green roof thermal performance (Sailor, 2008). This was utilised in modelling green roof performance detailed in Section13. This shows more than 30 different variables that determine how green roofs perform from a thermal exchange point of view. There are significant numbers of variables for elements of sustainable drainage performance, acoustic performance, whole life costing, air quality, durability etc. This makes predicting their performance challenging.

From the review of information undertaken, it emerged that many of the papers currently available across the literature, tend to refer to ‘green roofs’ without truly acknowledging all the different permutations and green roof build-ups that are possible. Unfortunately, this means that the repeatability can often be questioned. Some of the reasons for their questionable repeatability are:

- That the green roof type and build up is not always made explicit
- Experiments are often conducted outside and exposed to the weather and general climate.
- Information on the period of study, weather and climate is often not included

Figure 12—3 shows from a sample of green roof literature reviewed by Hampshire et al (2011) on thermal and sustainable drainage aspects that a significant number were not explicit about what type of green roof was being analysed. This is particularly evident for thermal performance where approximately 25% of the papers reviewed did not specify what type of roof it was. Detailed build-ups were not available for a larger percentage of the papers. This is problematic and often ignored across the academic literature. Furthermore, it means that the results cannot be taken and used to inform green roof design and anticipated performance in practice, as one cannot take the results of the experiments and attempt to consider how a similar roof might perform, as the reader does not know details of the roof type that has been researched in such papers.

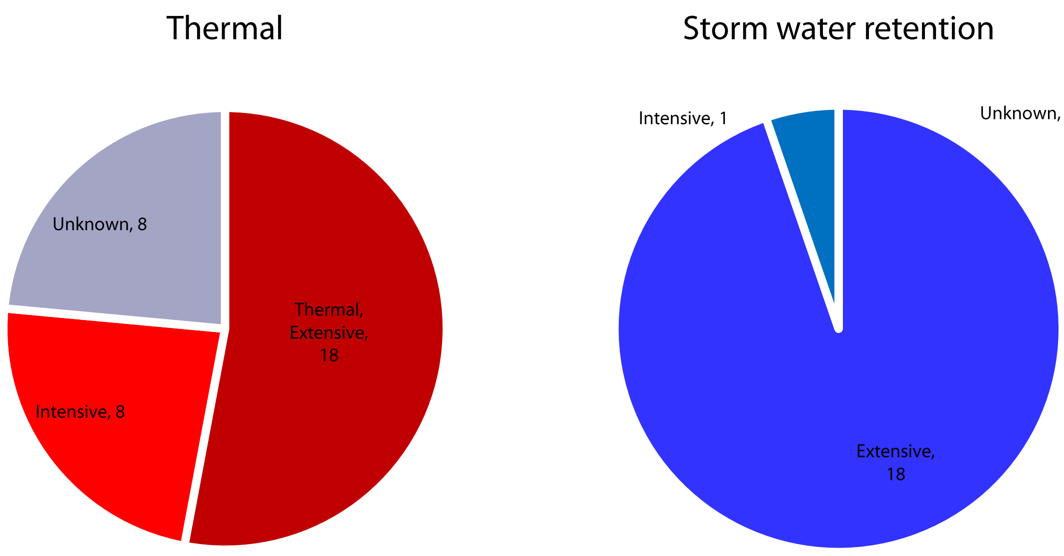


Figure 12—3 Green roof types of roofs experiments shown across the literature

Therefore, one aspect of this work, is to provide a quick reference guide to all the different green roof types, along with their build up that have been experimented on across the literature, classified by climate type, with the main findings easily accessible. Hopefully this will begin to address concerns that other authors have expressed and could provide the start of a common ground for reporting green roof research. This was highlighted by Dvorak and Volder (2010) as an important future development.

Additionally, comparison of green roof with other roof types is also required in many aspects of performance to provide evidence of the benefits and inform decision making. This is a rare occurrence in this field. Additionally, much of the research referenced was undertaking experimental work, however it is considered that this is not necessarily done in a coordinated way, meaning that research is often repeated for similar climate types and roof build-ups. However, some climate types and roof build ups have significantly less data, meaning that if a practitioner is working in a different region, then there is not much academic research to support green roof selection based on their performance.

In summary, many aspects of green roof performance have been explored over recent years, with literature growing significantly over this period. It is clear from the literature that green roofs impact positively on many attributes typically considered to be related to sustainability. Also emerging from the literature is that green roof performance is significantly less well understood in comparison to more traditional roofing options, which are non-living and tend to perform in ways that are much easier to assess and model. Therefore, the section has presented the latest research in different areas of performance of green roofs and also presented possible ways of assessing the performance of such roofs in these areas, building upon leading research. In some areas however, much research is still required and no generalisable equations to define performance are yet available.

12.5 Conclusion

This section has presented a method of acquiring the most climate specific and relevant green roof data from past research. This has involved, in many cases, the researcher categorising the research according to the research type (i.e. lab experiment, field experiment, modelling), the method, study location, climate type, season and duration, the roof build up and substrate depth and other findings of the work, which has enabled a structured dataset to be established that can be used to inform roof decisions.

The next section considers modelling techniques which can also provide guidance on the performance of roofs in different climates.

13 Part 2: Development of an approach to model performance

13.1 Introduction

One of the challenges of the design process, as detailed in the literature review in Section 2.3.3, is that the ability to influence sustainability is highest at the start of the design process (Reed and Gordon, 2000, Schade et al., 2011). However, this is when information on the performance of options is normally lacking (Thompson and Bank, 2010). Typically, computation modelling is done in the later design stages on perhaps one or two options to verify the performance of the design, but if modelling is to influence decisions at the start of projects, the modelling needs to be done quickly at the start of the design process across many options. Therefore, the approach to sustainable roof selection would benefit from an approach which allows roof performance to be modelled quickly, so that results can be applied at the earliest stages of the design process.

Building simulation programmes now exist, which allow the thermal performance of building materials and the associated impacts on surface temperatures of materials and air temperatures inside buildings to be modelled. This has commonly been possible for many traditional building materials which are inert and non-dynamic in their nature. However, live systems such as those demonstrated by green roofs are much more difficult to model.

However, as outlined in the literature review, authors such as Sailor (2008) and Scherba et al. (2011) have now made this possible and their results have been validated. Unfortunately, modelling the performance of buildings can be a time consuming process and is not typically done at the earliest stages of design. Therefore, utilising modelling to inform concept design is often not undertaken. Additionally, assessing the options of numerous layouts and systems can be a very time consuming process. Therefore, this research has developed an approach of utilising the power of modelling to inform decision making at the earliest stages of the project for a set of roof options.

13.2 Method

The method for this section was to undertake computer modelling of various systems and develop a database of results include these results which can be rapidly selected and included to provide information for undertaking design decisions. This section will describe the assumptions made and the techniques used.

The EnergyPlus building simulation program (Lawrence Berkeley National Laboratory, 2013) was chosen to model the impacts of green roofs on building performance. This is a widely used program in both academia and industry for modelling the heating, cooling and annual energy consumption of buildings. A list of authors that have used this program for research purposes are included on the US Department of Energy EnergyPlus website (US Department of Energy, 2014). The reason for this is that the programme now contains a module for modelling the impact of green roofs on the performance of buildings (Sailor, 2008). This can perform calculations, which include finding the surface temperatures of surfaces and determining the heat fluxes for roofs, which are useful for understanding impacts on the urban heat island effect and the energy required to keep a building within a certain temperature range. Additionally, it can calculate the required water input to maintain a specified soil saturation level. Whilst the output of heat-fluxes and watering requirements are not available through the standard releases of EnergyPlus, the researcher obtained the Fortran 90 source code and made modifications, so that the required variables were output when the bespoke version of the programme was recompiled.

Utilising the bespoke version of EnergyPlus, it was possible to set up a model that quantified the performance of green roofs and also more traditional roof systems for a particular climate type. To do this two input files are required to run the model utilising EnergyPlus. These are as follows and discussed in the following sections:

- The building input data file: This contains information on the building geometry, the materials used for the building constructions such as walls, windows, roofs, etc. It essentially describes all aspects of the building apart from the climate in which it is located, which is given in the weather file.
- The weather file: This contains information on the climate for the project’s location. However, this does not typically include rainfall.

13.2.1 Building input file

In order for the impact of the roof only to be assessed on the model runs, a simple ‘box’ model was set up, where the only variables was a change in the roof type. As we were primarily interested in the change of the systems from the structure upwards, a common roof structure was also used. To ensure that reasonable and generic insulation levels were used, the model was based upon standard specified constructions as outlined in Torcellini P et al. (2008). These consider constructions based upon the widely used ASHRAE standards. An image of the model assumed is shown in Figure 13—1.

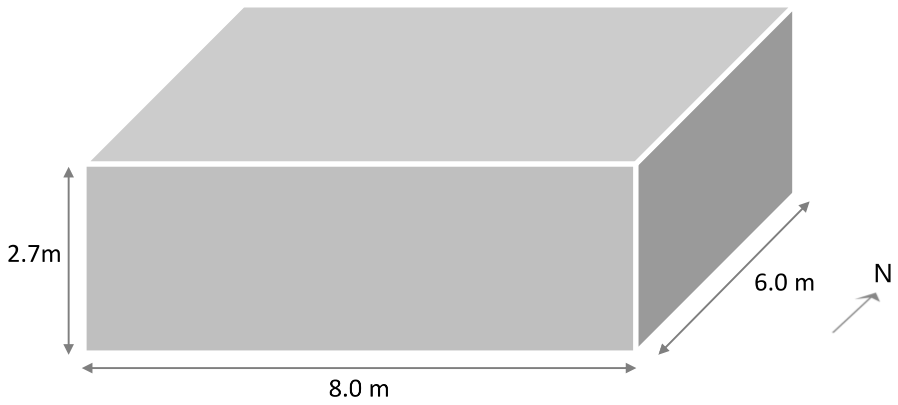


Figure 13—1 Layout and dimensions of EnergyPlus model

The following roof types were then set up, these were all based upon the standard model as shown above.

- Aluminium Coating
- Asphalt
- Black bitumen
- Cement Tile
- Grey EPDM
- Light Gravel
- Simple Green Extensive (10-40%) moisture content (4 models)
- White Coated Gravel
- White Concrete
- White Granular Bitumen
- White PVC membrane

All assumptions for all the systems selected are included in the roof decision support tool. An example is shown in Figure 13—2. It should be noted that due to the weather files used for EnergyPlus typically not having rainfall information, this is not accounted for in the green roof model. The way this is accounted for is simply by ensuring the moisture content of the soil is maintained at a certain saturation. Therefore four saturations have been modelled from 10-40% and the EnergyPlus source code has been modified to allow the water requirement to maintain these levels to be output. This will be utilised when considering whether the roof requires watering and if so how much watering will be required. A simple post run calculation of watering requirement is considered where rainfall data is available, through comparing the evapotranspiration rates of the plants (calculated through EnergyPlus) with annual rainfall. Any associated shortfall is considered to have to be met with watering the green roof and the final amount is calculated by dividing this amount by the efficiency of the irrigation technique.

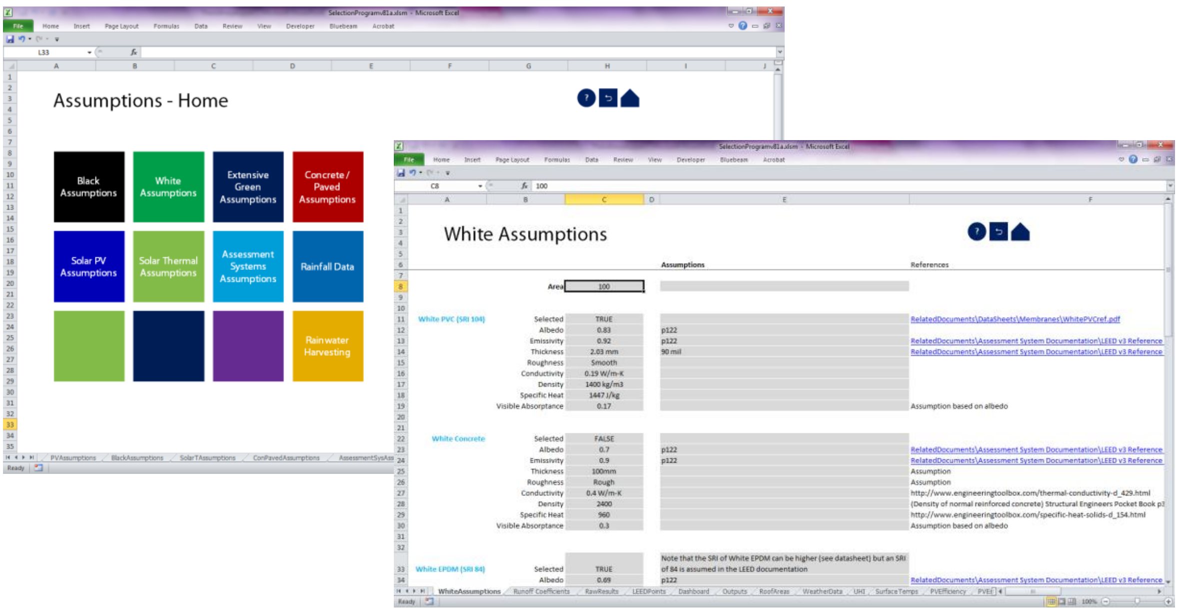


Figure 13—2 Typical assumption home page and typical example assumptions page

PV systems were also modelled, however this was not directly done on the building models, but instead as a stand-alone system. This allows the rapid calculation of lots of different orientations ranging from 0-90 degree inclination in 15 degree increments for 8 different orientations (N, NE, E, SE, S, SW, W, NW) as shown in Figure 13—3. Thus a total of 49 different orientations and inclinations were modelled for each panel (the panels at all directions are equal when horizontal) and thus this was counted once.

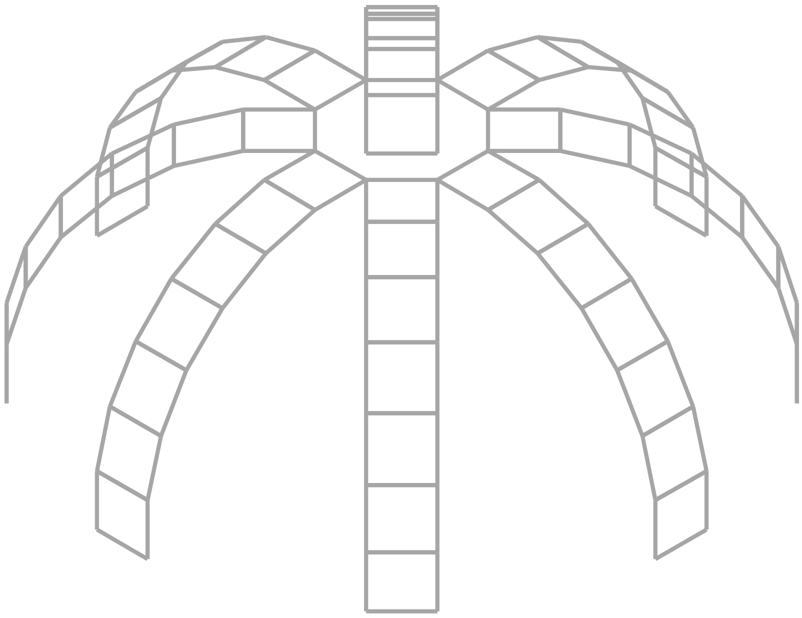


Figure 13—3 Model set up to calculate output of various inclinations on solar PV and thermal systems

Additionally, the same structure of model was utilised to calculate the incident solar radiation on each surface, which could then be utilised to undertake bespoke assessment of solar PV output for systems with different efficiencies to those above, albeit with slightly less accuracy as they would not be utilising the Sandia model as used by energy plus, which accounts for the reductions in PV output based on the temperature of the panels (see Appendix M). The solar incident radiation can also be utilised with simple rules of thumb models to calculate the output of Solar Thermal Systems. A figure showing the setup to be able to rapidly calculate this is shown in Figure 13—3.

The benefits of utilising a panel type already in the system are that the model then gives details on the temperature of the panels, which is used in the calculation of urban heat island effect.

The following PV systems were modelled.

- Sanyo HIP
- Sharp
- Yingli

The assumptions are shown in Figure 13—4. The full assumptions for use in the Sandia model are included within the EnergyPlus package and dataset.

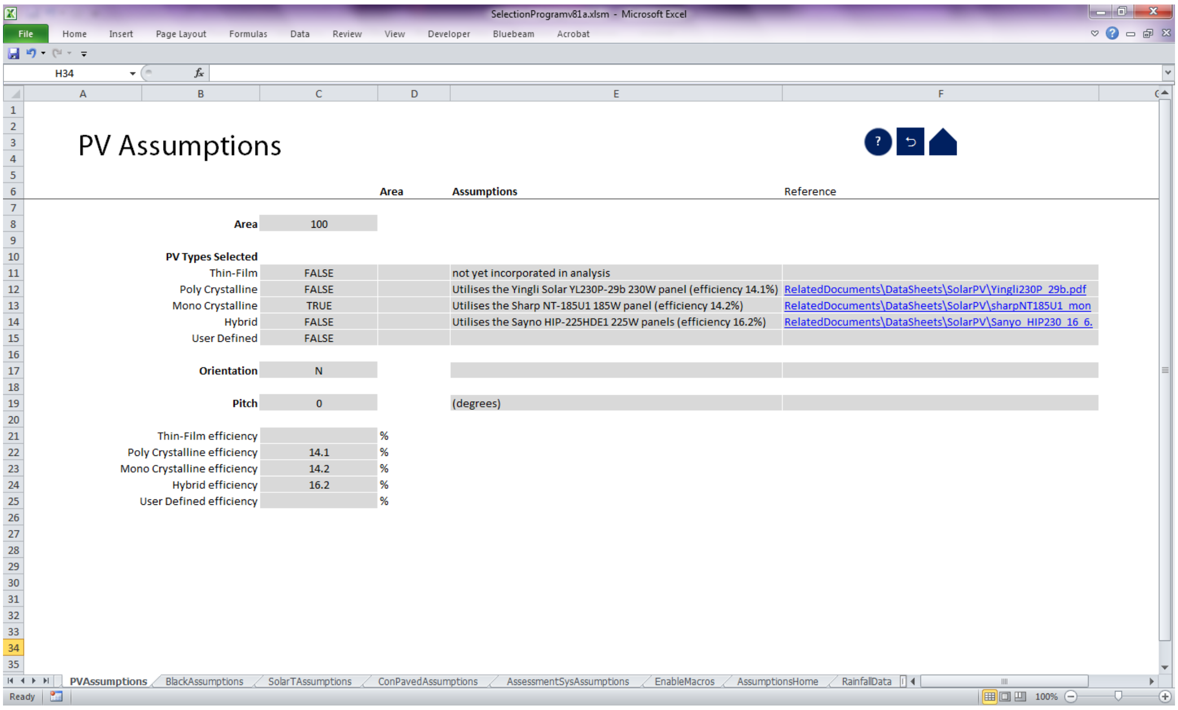


Figure 13—4 PV assumptions

The above two geometries, one for the performance of the roofing membranes and systems (Figure 13—1), the other for the performance of solar photovoltaics systems (Figure 13—3) were utilised to provide information on the performance of:

- Energy performance of the roof
    - Energy Production (electricity and hot water)
    - Energy consumption
- Roof temperatures (proxy for impact on urban heat island effect)
- Watering requirements of green roofs

Additionally, some of the above can be quantified to calculate the cost / income of some roof types and thus also plays a part in the in-use aspects of whole life costing. The in use costing aspects would require a significant number of assumptions and are not included here.

13.2.2 The weather files

In addition to the building input file, a second file is required for EnergyPlus to be able to calculate the above outputs for a specific location; this is the weather file. This contains hourly information regarding the climate at a certain location. The EnergyPlus team have made weather files available for more than 2100 locations around the globe, with over 1000 in USA, and over 1000 in 100 other countries (US Department of Energy, 2013). This provides a good global coverage of the climate at these locations. Typically a weather file is available at a location near most projects. Therefore, it is this database of weather files that will be utilised. There is a free tool for establishing the nearest weather files to a given site, which utilises the Google Maps Application Programming Interface (Bull, 2012). A selection of weather files were used across all the different models. This was done in an arbitrary way, selected for the projects that the Sponsoring Organisation works in the most. However, this could be expanded to include all weather files, providing that there was adequate storage for all the results files, which with numerous variables can be quite large in size.

13.2.3 Standardised approach

In order to rapidly assess many options, the same building input files with the different roof options were modelled through a batch run utilising the “simulate group” option in EnergyPlus. This allowed many input files, with their different roof options to be run simultaneously without the requirement of the researcher running each model separately and filing the results accordingly, which would have been an extremely time consuming process. A standardised folder structure was set up, which included the results for each weather file to be identified. Additionally, the weather files utilised for each country were stored in a standardised way utilising a country’s Alpha-3 codes, which abbreviate country names to a three letter code, utilising the ISO 3166 standard (ISO 3166-3, 1999). This standardisation was important, to allow the future development of an approach and accompanying decision support tool to automatically get the most relevant data based on a user’s input on location of interest.

Such an approach allowed context specific data for the assessment of green roofs to be generated quickly and in a standardised way which meant that an approach could be developed to access data and automated in the form of a DST.

The results were output in the standard way from EnergyPlus and filed utilising a standardised filing system as described above. An example of the output files created for each location is shown in Figure 13—5. This shows a significant number of files. Different roof types have a different set of outputs.

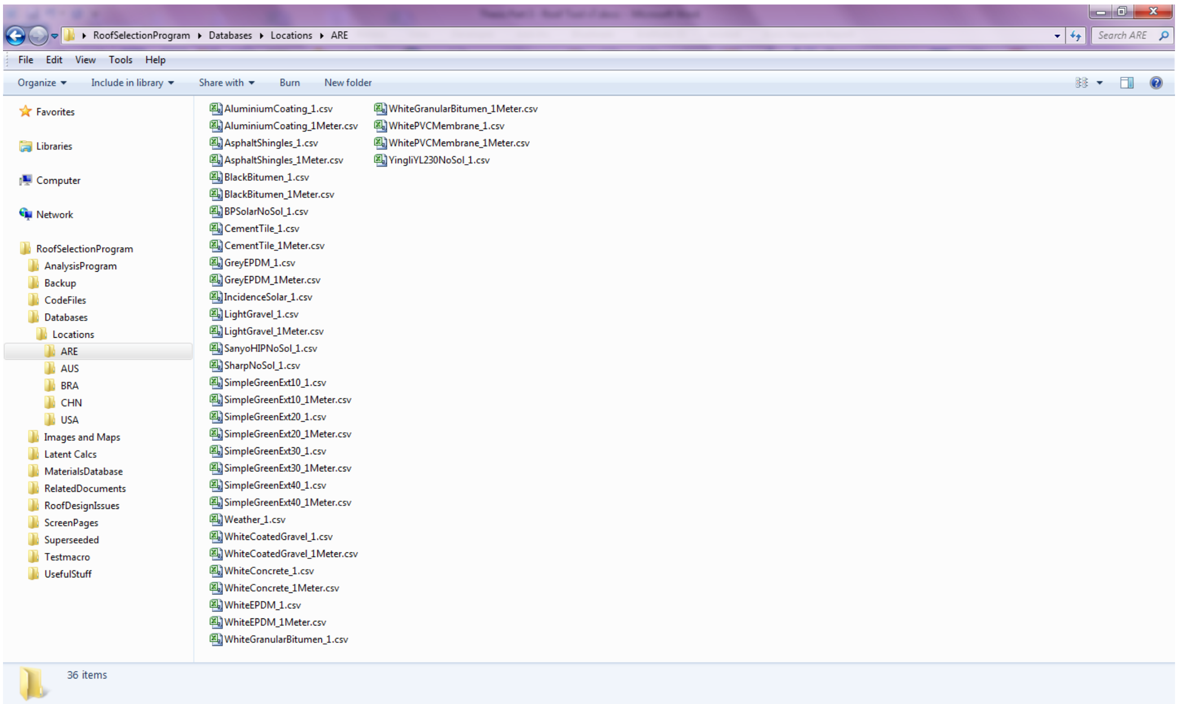


Figure 13—5 Typical set of results files for a given location

The individual variables calculated in each results file vary depending on the type of model to provide the results of interest. For example, different variables are required for some elements of green roof performance to that of more standard roof types. The different file types are shown in Table 13—1 along with the files that are output by the EnergyPlus program. These are further explained under the following headers.

Table 13—1 Roof types and classification for results files

Information Files	Standard Roof Type Files	Green Roofs Files	Solar Photovoltaic Files
Weather Solar Incidence	Aluminium Coating Asphalt Black bitumen Concrete roof Grey EDPM Light Gravel White Coated Gravel White Concrete White EPDM White Granular Bitumen White PVC Membrane	Extensive (10% Moisture) Extensive (20% Moisture) Extensive (30% Moisture) Extensive (40% Moisture)	BP Solar Sanyo HIP Sharp Yingli

13.2.4 Information files

"Information files" include outputs that are required for post calculation for some elements of roof performance. Weather files typically contain information on climatic variables, such as 'dry bulb temperature (°C)', relative humidity (%), 'wind speeds' etc. and are typically useful as a sense check to compare results against.

For example "Solar Incidence" calculates the solar radiation incident on all the surfaces outlined in Figure 13—3 and allows the calculation of Solar PV and Solar Hot Water systems based on calculated or user input efficiencies in the Roof Decision Support Tool. This is not calculated utilising EnergyPlus for simplicity.

13.2.5 Standard roof types files

All *'Standard Roof Types'* contain the same variables in the results files, which include the following key variables. The main ones for consideration in the roof decision support tool include:

- heating energy required to maintain a temperature of at least 20°C (Joules)
- cooling energy require to maintain a temperature of less than 24°C (Joules)
- surface temperature of the external roof surface (°C)
- external roof surface thermal radiation heat rate per area (W/m^2)

It should be noted that all the variables are calculated on an hour basis, meaning that there are 8760 values for each variable over the course of a one year period that the model is run for.

13.2.6 Green roof files

"Green roof" results files contained 62 different variables. The following key variables are used to calculate the impact on urban heat island effect, watering demand, runoff and energy consumption within the building.

- Soil
    - Temperature (°C)
    - Sensible Flux (W/m^2)
    - Latent Flux (W/m^2)
- Vegetation
    - Temperature (°C)
    - Sensible Flux (W/m^2)
    - Latent Flux (W/m^2)
- roof runoff

- evapotranspiration (m/hour/m^2)
- heating energy required to maintain a temperature of at least 20°C (Joules)
- cooling energy require to maintain a temperature of less than 24°C (Joules)

13.2.7 Solar photovoltaic files

"Solar Photovoltaic" results files contained the following information:

- For panels facing (N, NE, E, SE, S, SW, W, NW) and angle of orientation (0° - 90° in steps of 15°); a total of 49 combinations of orientation and inclination.
    - System Efficiency (%)
    - Cell Temperature (°C)

This is used to calculate the energy output from the panels.

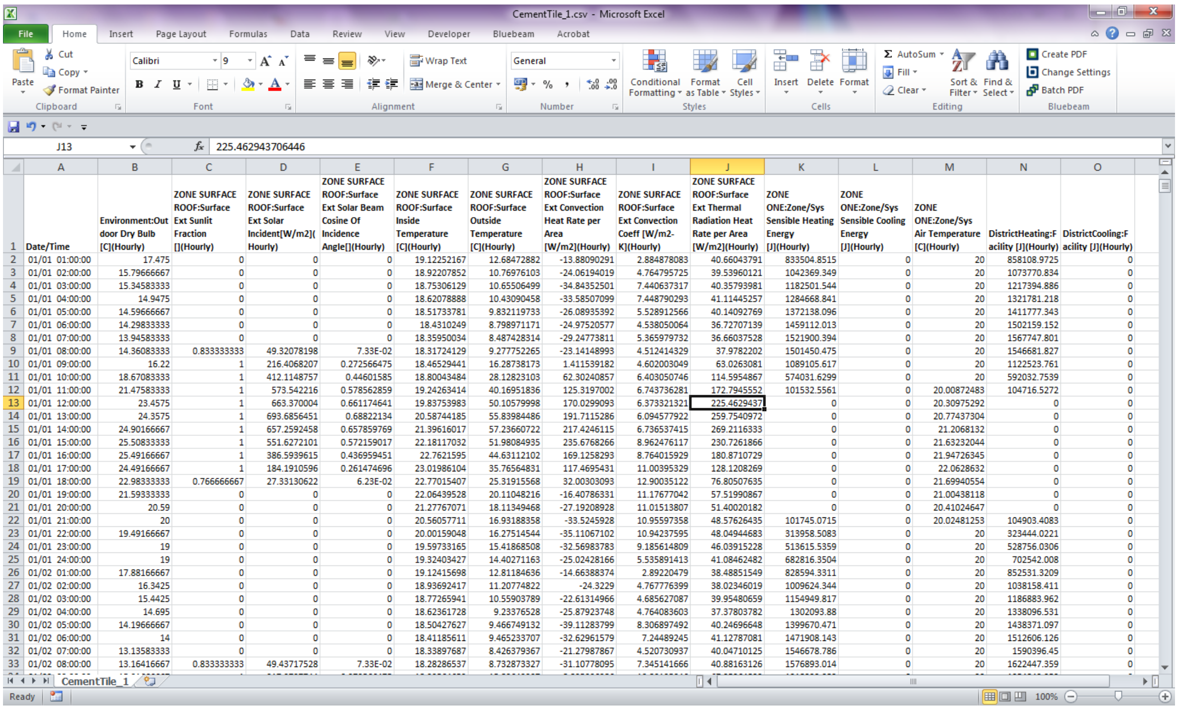
13.3 Results

The results files outlined above provide the required raw data to be able to calculate values for the following aspects of the decision tool:

- Energy
    - Energy Production
        - Hot water energy
        - Electrical Energy Production
    - Energy Use
- Urban Heat Island Effect
- Watering requirement

Additionally the energy implications for EAMs, BREEAM, LEED and Estidama will be estimated utilising the outputs of the models, although it should be noted that these are dependent on many other things relating to aspects broader than the roof.

An example output for one of the "standard roof" types analysed is shown in Figure 13—6. This shows a small part of the output, which for each variable is calculated for each hour of the year. The performance of each roof option will vary on an hourly basis. This is a significant amount of data, especially considering the number of different options available. Additionally, this represents one roof type and does not consider that the decision maker may want to combine several roof types to make up a roof. Generating this data quickly at an early stage in the project life cycle can be challenging and furthermore analysing the data to inform decision making can be a challenge.



CementTile_1.csv - Microsoft Excel

J13 225.462943706446

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Date/Time	Environment:Outdoor Dry Bulb [C](Hourly)	ZONE SURFACE ROOF:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE ROOF:Surface Ext Solar Incident[W/m2](Hourly)	ZONE SURFACE ROOF:Surface Ext Solar Beam Cosine Of Incidence Angle[](Hourly)	ZONE SURFACE ROOF:Surface Inside Temperature [C](Hourly)	ZONE SURFACE ROOF:Surface Outside Temperature [C](Hourly)	ZONE SURFACE ROOF:Surface Ext Convection Heat Rate per Area [W/m2](Hourly)	ZONE SURFACE ROOF:Surface Ext Convection Coeff [W/m2-K](Hourly)	ZONE SURFACE ROOF:Surface Ext Thermal Radiation Heat Rate per Area [W/m2](Hourly)	ZONE ONE:Zone/Sys Sensible Heating Energy [J](Hourly)	ZONE ONE:Zone/Sys Sensible Cooling Energy [J](Hourly)	ZONE ONE:Zone/Sys Air Temperature [C](Hourly)	DistrictHeating:Facility [J](Hourly)	DistrictCooling:Facility [J](Hourly)
2	01/01 01:00:00	17.475	0	0	0	19.12252167	12.68472882	-13.88090291	2.884878083	40.66043791	833504.8515	0	20	858108.9725	0
3	01/01 02:00:00	15.79666667	0	0	0	18.92207852	10.76976103	-24.06194019	4.764795725	39.53960121	1042369.349	0	20	1073770.834	0
4	01/01 03:00:00	15.34583333	0	0	0	18.75306129	10.65506499	-34.84352501	7.440637317	40.35793981	1182501.544	0	20	1217394.886	0
5	01/01 04:00:00	14.9475	0	0	0	18.62078888	10.43090458	-33.58507099	7.448790293	41.11445257	1284668.841	0	20	1321781.218	0
6	01/01 05:00:00	14.59666667	0	0	0	18.51733781	9.832119733	-26.08935392	5.528912566	40.14092769	1372138.096	0	20	1411777.343	0
7	01/01 06:00:00	14.29833333	0	0	0	18.4310249	8.798971171	-24.97520577	4.538050064	36.72707139	1459112.013	0	20	1502159.152	0
8	01/01 07:00:00	13.94583333	0	0	0	18.35950034	8.487428314	-29.24773811	5.365979732	36.66037528	1521900.394	0	20	1567747.801	0
9	01/01 08:00:00	14.36083333	0.833333333	49.32078198	7.33E-02	18.31724129	9.277752265	-23.14148993	4.512414329	37.9782202	1501450.475	0	20	1546681.827	0
10	01/01 09:00:00	16.22	1	216.4068207	0.272566475	18.46529441	16.28738173	1.411539182	4.602003049	63.0263081	1089105.617	0	20	1122523.761	0
11	01/01 10:00:00	18.67083333	1	412.1148757	0.44601585	18.80043484	28.12823103	62.30240857	6.403050746	114.5954867	574031.6299	0	20	592032.7539	0
12	01/01 11:00:00	21.47583333	1	573.542216	0.578562859	19.24263414	40.16951836	125.3197002	6.743736281	172.7945552	101532.5561	0	20.00872483	104716.5272	0
13	01/01 12:00:00	23.4575	1	663.370004	0.661174641	19.83753983	50.10579998	170.0299093	6.373321321	225.4629437	0	0	20.30975292	0	0
14	01/01 13:00:00	24.3575	1	693.6856451	0.68822134	20.58744185	55.83984486	191.7115286	6.094577922	259.7540972	0	0	20.77437304	0	0
15	01/01 14:00:00	24.90166667	1	657.2592458	0.657859769	21.39616017	57.23660722	217.4246115	6.736537415	269.2116333	0	0	21.2068132	0	0
16	01/01 15:00:00	25.50833333	1	551.6272101	0.572159017	22.18117032	51.98084935	235.6768266	8.962476117	230.7261866	0	0	21.63232044	0	0
17	01/01 16:00:00	25.49166667	1	386.5939615	0.436959451	22.7621595	44.63112102	169.1258293	8.764015929	180.8710729	0	0	21.94726345	0	0
18	01/01 17:00:00	24.49166667	1	184.1910596	0.261474696	23.01986104	35.76564831	117.4695431	11.00395329	128.1208269	0	0	22.0628632	0	0
19	01/01 18:00:00	22.98333333	0.766666667	27.33130622	6.23E-02	22.77015407	25.31915568	32.00303093	12.90035122	76.80507635	0	0	21.69940554	0	0
20	01/01 19:00:00	21.59333333	0	0	0	22.06439528	20.11048216	-16.40786331	11.17677042	57.51990867	0	0	21.00438118	0	0
21	01/01 20:00:00	20.59	0	0	0	21.27767071	18.11349468	-27.19208928	11.01513807	51.40020182	0	0	20.41024647	0	0
22	01/01 21:00:00	20	0	0	0	20.56057711	16.93188358	-33.5245928	10.95597358	48.57626435	101745.0715	0	20.02481253	104903.4083	0
23	01/01 22:00:00	19.49166667	0	0	0	20.00159048	16.27514544	-35.11067102	10.94237595	48.04944683	313958.5083	0	20	323444.0221	0
24	01/01 23:00:00	19	0	0	0	19.59733165	15.41868508	-32.56983783	9.185614809	46.03915228	513615.5359	0	20	528756.0306	0
25	01/01 24:00:00	19	0	0	0	19.32403427	14.40271163	-25.02428166	5.535891413	41.08462482	682816.3504	0	20	702542.008	0
26	01/02 01:00:00	17.88166667	0	0	0	19.12415698	12.81184636	-14.66388374	2.89220479	38.48851549	828594.3311	0	20	852531.3209	0
27	01/02 02:00:00	16.3425	0	0	0	18.93692417	11.20774822	-24.3229	4.767776399	38.02346019	1009624.344	0	20	1038158.411	0
28	01/02 03:00:00	15.4425	0	0	0	18.77265941	10.55903789	-22.61314966	4.685627087	39.95480659	1154949.817	0	20	1186883.962	0
29	01/02 04:00:00	14.695	0	0	0	18.62361728	9.23376528	-25.87923748	4.764083603	37.37803782	1302093.88	0	20	1338096.531	0
30	01/02 05:00:00	14.19666667	0	0	0	18.50427627	9.466749132	-39.11283799	8.306897492	40.24696648	1399670.471	0	20	1438371.097	0
31	01/02 06:00:00	14	0	0	0	18.41185611	9.465233707	-32.62961579	7.24489245	41.12787081	1471908.143	0	20	1512606.126	0
32	01/02 07:00:00	13.13583333	0	0	0	18.33897687	8.426379367	-21.27987867	4.520730937	40.04710125	1546678.786	0	20	1590396.45	0
33	01/02 08:00:00	13.16416667	0.833333333	49.43717528	7.33E-02	18.28286537	8.732873327	-31.10778095	7.345141666	40.88163126	1576893.014	0	20	1622447.359	0

CementTile_1

Figure 13—6 Example output from the EnergyPlus program.

The impacts of the roof on the internal energy required to cool and maintain a space at a maximum of 24°C are shown in Figure 13—7 for three roof types, which include concrete paving, black bitumen, and White EPDM. The results are to be expected for a summer day in a hot climate. It shows the white EPDM roof performing the best. In a winter situation in a cooler climate, the black roof is likely to perform better in the sunshine, as less heating will be required.

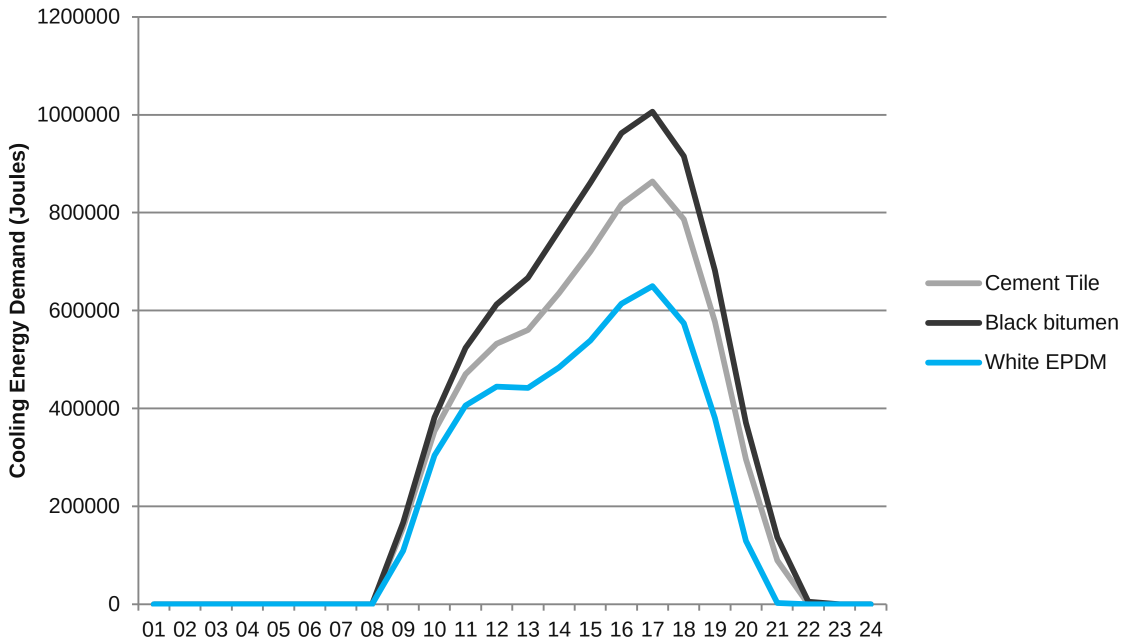


Figure 13—7 The performance of the same options at the same time with respect to the cooling energy requirement of the model room

Whilst standard programs give the output similar to that shown above they do not allow for the user to compare several attributes at once, make obvious values that represent annual performance, or allow weighting of attributes to inform decisions. Therefore, whilst programs such as EnergyPlus can provide useful information, they are somewhat removed from the decision making process.

13.4 Discussion

The calculation method allowed the rapid calculation of roof performance information utilising batch runs. Once the runs had been completed for the numerous options across climate types, the data is then stored in a standardised and accessible folder structure which is useful to allow the designer to find information quickly and also import the data automatically into the DST.

A review of the outputs gave consistent results with, white roofs for example performing better from an energy and heat perspective in hot sunny conditions. However, this would be expected by utilising an established building modelling software to perform the calculations. Thus the approach worked well at gaining quantitative information of the performance of roofs in several attributes. Additionally, results agreed with the output of a paper by Scherba et al. (2011) who looked at the performance of different roof options for a particular location with respect to urban heat island effect. These results were also validated with experimental studies. Undertaking validation of the results of established building simulation programs is considered outside the scope of this research, however, it is proposed as an area of further work to do this for the performance of green roofs. One suggestion would be to undertake further validation of the EnergyPlus model for green roofs developed by Sailor (2008) with the results from experimental study in numerous climate types by different authors, thus trying to replicate the results of studies highlighted in Section 12.

Whilst the method appears to give reliable quantitative information regarding the performance of different roof types, a way of comparing the different options was required, which also allows comparisons across different roof types and combinations of roof types to be put together. The only way to understand the performance of different combinations of options utilising a building energy program such as EnergyPlus would be to change the model to include a combination of different roof options and re-run the model accordingly. This could be quite a time consuming process to undertake at the start of design. Additionally, the programme gives a wealth of outputs, but the performance fluctuates over the course of a day and also over the seasons so guidance is required on which figures to utilise to inform decision making. For example, for some elements of design it may be peak temperature that is of interest to the decision maker, as that can be utilised to inform the capacity required for a cooling system.

Other limitations of the building simulation programs used are that there is no method of weighting the importance of results across numerous attributes. They primarily just provide information which can be vast and overwhelming. It is considered more of a forecasting type approach in relation to French and Geldermann (2005), as shown in Figure 4—2 in Section 4.2, which is considered to provide information on the consequences of potential strategies but not a method of evaluation and ranking in relation to other strategies. Statistical analysis and combination of the results in relation to the values of the stakeholders is still required in order to make the results useful to inform decision making. The outputs require careful choice, analysis and a method of weighting the performance. An approach to summarising, structuring and incorporating this data to inform decision making through consideration of an MCDA technique is discussed in Section 14. Some post analysis is often required to do this that is not always possible in the building simulation program, such as EnergyPlus. To do this manually is a time consuming process, potentially manipulating the output of many different files to get the appropriate information for a decision. This can be problematic as time is generally limited, and it is rare that designers would get the required time to test a variety of options and their impact on design. Additionally, this can lead to mistakes. Therefore, the information ideally would be incorporated into a decision support tool to inform decision making to assess roof options. The next section considers the development of such an approach.

13.5 Conclusion

This section has developed a method for rapidly acquiring data on numerous different roof types utilising the EnergyPlus simulation program. This makes use of various modelling methods and can assess the performance of roof systems including green roofs on numerous attributes. It is considered that this provides additional information on the performance of roof options, which can be statistically analysed over the course of a year to provide roof performance data, which can be used to inform decision making. It is intended that this feeds into the approach that is developed to inform sustainable roof selection in the next section of the thesis.

14 Part 2: Development of an approach and decision support tool for sustainable roof selection

14.1 Introduction

Building on the work undertaken in the action research case study in Section 11, this section takes some of the aspects that require further work and develops approaches to address some of these issues.

It also aims to bring all the elements of the research undertaken together to achieve the overall research objective *”to define a pragmatic realist approach to decision making to inform sustainable roof selection in the context of building design”*. In doing so, it aims to provide an approach to bringing together values of stakeholders, brief requirements with respect to roofs, and quantitative data on the performance, through techniques as outlined in Sections 12 and 13.

This section presents the development of a decision support approach and tool to inform green roof selection based on their quantifiable benefits for a particular region’s location and climate. It also allows for integration and weighting of the various characteristics based on the needs of the project.

It is important to note that the philosophy in which this work is conducted agrees with that of Ralph Keeney, who states that facts are required in addition to values, *“Quite simply, deciding what is important requires value judgements. Deciding how to achieve a high-level objective requires factual knowledge”* (Keeney, 1992). However, this is also combined with elements of alternative focused thinking, which is highlighted through the SMART approach presented in Goodwin and Wright (2009).

This section outlines the techniques applied and assumptions behind creating an approach to roof selection and prototype DST. It also explains how it fits into a larger process to inform roof selection on projects. The approach is tested through application on a case study project. The approach to sustainable roof selection is incorporated into a decision support tool, which automates many aspects of the process with the intention of speeding up the approach and also simplifying the analysis of information.

14.2 Method

The methods utilised to develop the tool primarily involve a review of the literature to compile a list of secondary data types on the performance of roofs to identify important characteristics of context which impact on their performance. Additionally, the various aspects are considered against how they address current gaps in the research.

Two MCDA techniques were considered for use in the approach to sustainable roof selection and accompanying DST. These included the Analytic Hierarchy Process (AHP) (Saaty, 1990) and Simple Multi-Attribute Rating Technique (SMART) (Edwards, 1971). SMART with Swings (SMARTS) (Edwards and Barron, 1994) was chosen as the method to inform the development of the DST, as it was considered simpler to implement than AHP, and also less time consuming to undertake the analysis than utilising the pairwise comparison technique included in AHP.

Marttunen and Hämäläinen (1995) reviewed MAUT, SMART and AHP methods for decision analysis for the assessment of environmental impacts in water development projects in Finland. SMART was chosen over AHP because AHP proved too time consuming with stakeholders and it is for a similar reason why SMART was chosen as the weighting technique for this piece of research. Additionally, with potentially large number of criteria it was considered that AHP involving pairwise comparison would be a time consuming process.

Additionally, it also benefited from the swing weighting method that considered the performance range of different options in the weighting procedure. Additionally, SMART does not predetermine the weights given to a linguistic scale as considered in the AHP process. For example, if A is considered ‘weakly more important’ than B it is weighted 3 times more important.

SMART is considered to be more internally consistent and also simpler to use. Additionally, it allows users to define their own appropriate weightings using the simple swing weighting method. Therefore it was selected as the most appropriate technique. It is also widely applied due to its relative simplicity and transparency. Simplicity and transparency is considered of paramount importance in environmental, multi-stakeholder decisions (Hajkowicz, 2008) Therefore, SMART was chosen as the basis of the decision support tool. SMART consists of the following eight stages (Goodwin and Wright, 2009):

1. Identify the decision maker
2. Identify the alternative courses of action
3. Identify the attributes that are relevant to the decision problem

4. Measure the performance of alternatives on that attribute
5. Determine a weight for each attribute
6. For each alternative, take a weighted average of the values assigned to that alternative
7. Make a provisional decision
8. Perform sensitivity analysis

These also align with many of the stages outlined by McCourt (2007) and are based upon Keeney's value focused thinking (Keeney 1992).

The stages were slightly modified and used to provide the structured approach to sustainable roof selection. Modifications included incorporating a proceeding first stage which is considered applicable in this context. This is to identify how important the decision is. This is shown as *"Stage 0: Identify how important the decision is"* in Figure 14—1. Reasons for this are that if the decision is not that important, then undertaking significant analysis to inform roof selection may therefore become less appropriate.

Additionally, *"Stage 1- Identify the decision maker"* was left out of the approach. Whilst it is considered an important step early interviews with industry professionals showed confusion over who the decision maker regarding roof selection was, therefore the tool is intended to be used by many of the project's stakeholders in different ways. For example it is more likely that the Architect and Engineer will want to use the tool to inform system selection and design, through modifying the parameters and comparing the performance of different roof options explicitly. However, the Client and Project Manager may want to see the output of the tool when considering different options and maybe more involved regarding the selection of weightings. It is likely to be someone who is familiar with the project, and also someone who understands the different ways in which roof systems can influence the sustainability of a project. However, the different levels of outputs of such tools will probably be used differently to inform different decision makers. Therefore, it might be that graphical outputs, produced by the tool are given to the client or project manager to inform their decision making. The tool considers the context in which it will be used and the requirements of the decision makers.

Further changes include switching the order of *"Stage 2 - Identify the alternative courses of action",* and *"Stage 3 – Identify the attributes that are relevant to the decision problem"*. Emerging from the literature review in Part 1 of the research, stakeholder driven value based approaches to sustainability decisions was an area detailed as requiring further work from authors such as Cole (2000, 2005) and Kaatz et al. (2006). Value Focused Thinking (Keeney 1992) therefore seemed a suitable starting point for considering sustainable roof selection, first considering the values and what is important to the decision problem in order to inform the development of roof options.

Considering the above changes, Figure 14—1, shows the parts of the DST as mapped against SMART. Each 'box'/part in Figure 14—1 will be described in more depth in the following sections.

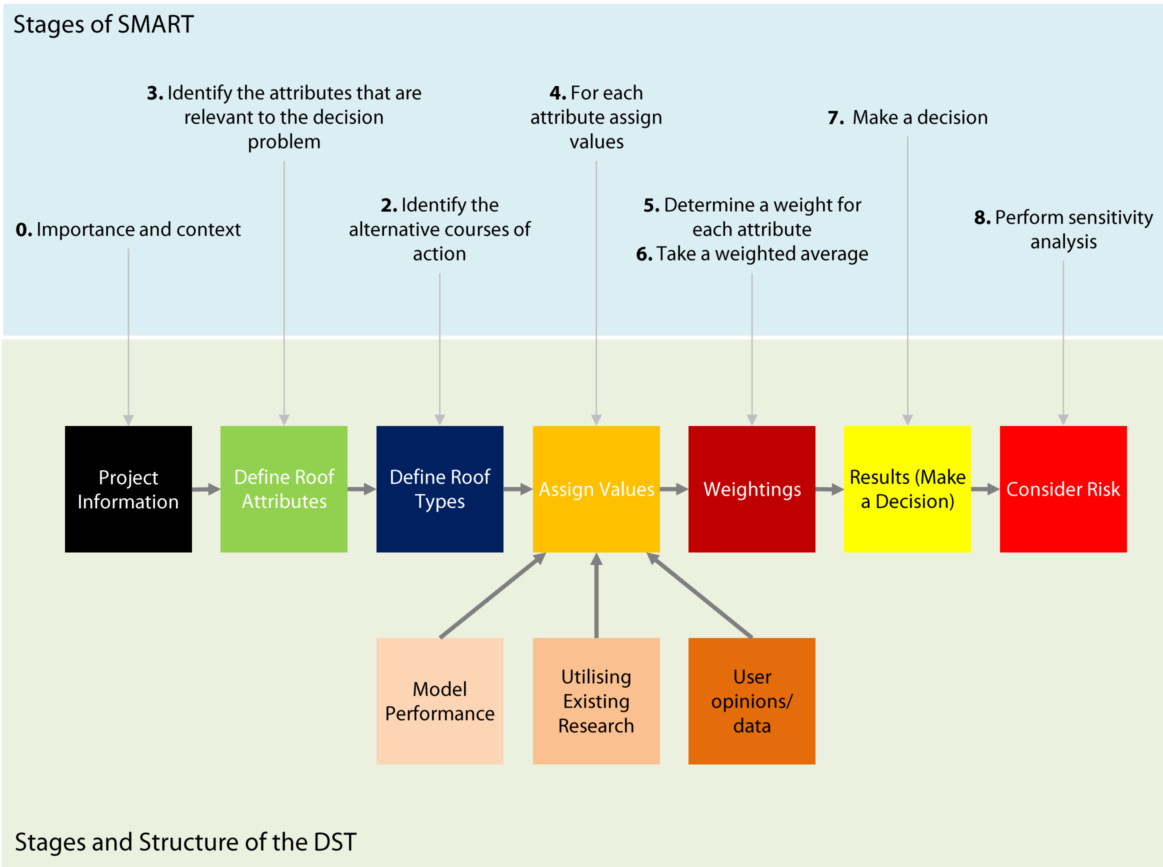


Figure 14—1 The main parts of the decision making tool (DST) mapped against the stages of SMART

One of the main challenges of the research is the need to make decisions regarding sustainability at the start of the design process when there is the most opportunity to influence sustainability. This requires a DST that allows the rapid selection of roof attributes and the input of a range of roof system types. Then the tool is required to collate potentially vast amounts of context specific performance data for each roof system in order to compare the options. The DST has to be able to weight the importance of different roof attributes and summarise the performance across numerous objectives quickly and rapidly undertake sensitivity analysis on the weighted performance of numerous roof options.

In order to do this, it was considered necessary to standardise and automate parts of the SMART process. This would be beneficial in processing and summarising significant amounts of data for each roof system against numerous decision attributes. The DST is therefore a Microsoft Excel based tool that calculates the context specific performance of different roof systems for numerous decision attributes based upon information from numerous databases and the output of modelling. Excel was chosen as the platform as it is something that typically members of the design team have access to and are familiar using. Additionally, through Visual Basic for Applications (VBA) programming language it was possible to develop the appropriate level of functionality and was therefore considered a good platform to be able to rapidly collate the appropriate information.

The tool provides a way of allowing the user to choose from a list of roof attributes, which are discussed commonly across the literature and environmental assessment frameworks, as well as input their own context specific additional attributes if required. Therefore, the prototype DST interface has the flexibility to incorporate the values of the stakeholders of the project, but also provides guidance on which issues/attributes a roof tends to have an influence on. The tool also provides a way of selecting a local context and getting the most appropriate and relevant results rapidly, which is important in the early stages of design. It is intended that with further development the tool could be used ‘live’ in a design team meeting to guide the dialogue in a design workshop.

The approach to sustainable roof selection and prototype DST was built based on the requirements that were based on the research gap identified from previous work looking at:

- bring together the most appropriate roof information based upon the user’s input of location
- rapidly calculate the most appropriate singular values from the output of computational simulation through the EnergyPlus building simulation program

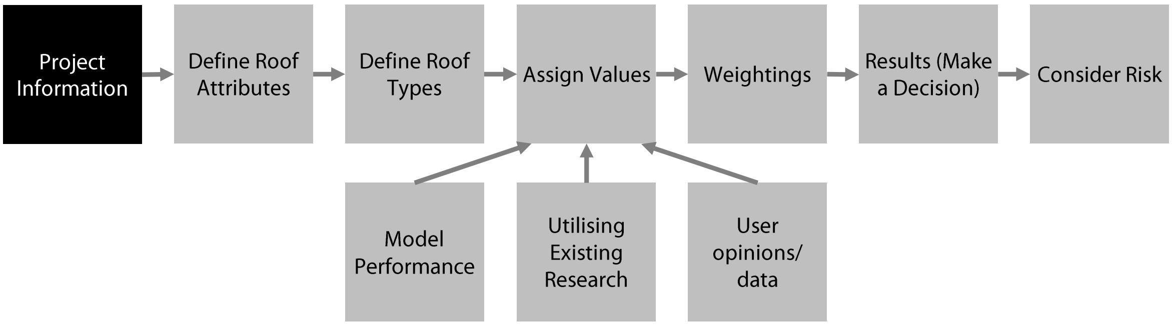
- have the ability to combine several different roof options over a roof area to make a multifunctional “roofscape”
- allow users to input their weightings based upon the results and automatically see the changes that this had on the ranking of different options
- show results clearly to the decision maker.

This section explains the various parts of the tool and the techniques that have been applied to bring together the appropriate information. It also explains how the decisions have been structured. It consists of the parts shown in Figure 14—1, which are explained in depth in this section and where appropriate demonstrated with a case study example. This shows the results of the prototype tool in use.

The approach to roof selection brings together a combination of secondary data, performance rules of thumb and computational modelling to provide context specific performance information on different roof options for buildings. This is brought together utilising elements of both value focused and alterative based decision making techniques. All data is referenced to the original research or database.

The rest of this section describes the various parts of the approach, which is incorporated and semi-automated within a prototype DST. In order to show where the reader is in the process a key is provided that shows the step of the approach being discussed in relation to Figure 14—1. This is included at the start of each section.

14.2.1 Project information



This part of the approach asks the users to provide information regarding the project, the location, the type of building that it is. This provides early information on how important the roof design and selection is and key facts that will be used to score the performance of the different roof options in different areas. For example, roof area and site area are two variables that are required to calculate the provision of biodiversity a green roof offers under the EAMs of LEED and BREEAM.

Additionally, through the inputs required above the importance of the performance of the roof on the overall performance of a building is likely to vary from project to project, depending on the type of the project. This was demonstrated as an important factor in Nelms et al. (2007). Three ratios are then given as a guide to predicting the influence of the roof decision on the overall project. This essentially aims to give a high level view on how important the roof choice is likely to be in the greater scheme of the project. These are as follows:

- ***Roof area to gross floor area ratio.*** The less this ratio is, the less ability the roof has to influence the performance of the space within the building.
- ***Roof area to site area ratio.*** The less this ratio is, the less ability the roof has to influence what happens on the project site. This is particularly of interest for external amenity space, biodiversity considerations and runoff from the site and is considered important with respect to LEED (US Green Building Council, 2009).
- ***Roof area to façade area ratio.*** The roof and facades provide the primary protection from the elements and the smaller this ratio is the less influence the roof has on thermal heat transfer and the impact on energy use in comparison to the facades; thus this is also an important ratio with respect to roof influence. This is also required for calculating some aspects of performance in relation to material use in assessment methods such as BREEAM (BRE, 2011).

This can be exemplified using the example in Figure 14—2, which demonstrates the different impacts the two example roofs will have on the project. Project A, could represent a typical two storey house. As can be seen, the 'roof area to floor area' and 'roof area to facade area' ratios are much higher than for Project B, representing a typical multi-storey office block. This is significant because the ability of the roof to influence the overall proportion of the building's energy consumption increases as the roof area to façade area percentage increases, as the roof becomes a larger proportion of the buildings surfaces for heat exchange. Additionally, the percentage of roof area to floor area is likely to significantly impact the proportion of the building's energy demands, which can be met through the installation of solar photovoltaic and solar thermal panels. Other factors such as the roof area to site area ratio are important, as the larger the percentage of roof area to site area as in the case for 'Project B', the less opportunity there is to integrate amenity space on the site, without utilising the roof. This is also true for incorporating biodiversity features. Thus the roof becomes more important for such considerations.

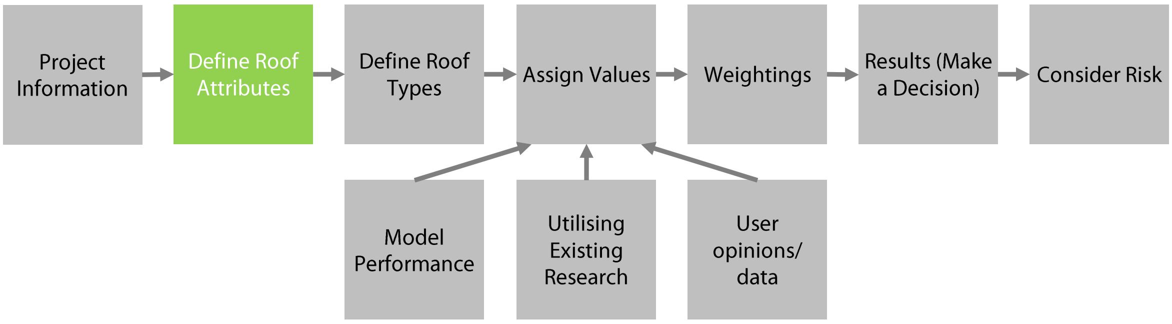
This is one of the reasons why decisions need to be considered on a project by project basis and there is no one size fits all answer. The prototype DST incorporates a simple calculation for assessing the importance of the roof based on the three ratios described on the previous page. This is not intended to be a comprehensive answer to how important the roof is in the context of the project, as this will be determined by the project's requirements, national and local legislation and many other factors, but an approximate guide as to the potential impact.

Other information which is required at this stage is the project location. This is so that the climate type and associated nearest weather file to the site can be identified to be able to model elements of performance or select the most appropriate research for roof types when they are selected later in the approach.

	Project A	**Project B**
Example	**2 Storey House**	**20 Storey Office Building**
Building Dimensions	6m (W) x 6m (D) x 6m (H)	15m (W) x 15m (D) x60m (H)
Site Area	20m (W) x 20m (D)	20m (W) x 20m (D)
Roof Area	36m^2	225m^2
Roof Area to GFA Ratio	50%	5%
Roof Area to Site Area Ratio	9%	56%
Roof Area to Façade Area Ratio	25%	6%

Figure 14—2 The importance of roof area

14.2.2 Define roof attributes



In order to select attributes to include in the prototype DST, the review of roof types and the implications regarding the performance of roof types were considered. This for example, built upon the criteria that affected roof performance from the numerous environmental assessment methods, including LEED, BREEAM and Estidama. The environmental assessment methods tend to be primarily environmentally focused and therefore, in addition to this, alternative decision attributes were identified through the literature review. These included additional attributes on the economic and social aspects, which are commonly considered in sustainability. A decision tree was then developed as shown in Figure 14—3. An expansion of further levels of the environmental decision attributes are then shown in Figure 14—4.

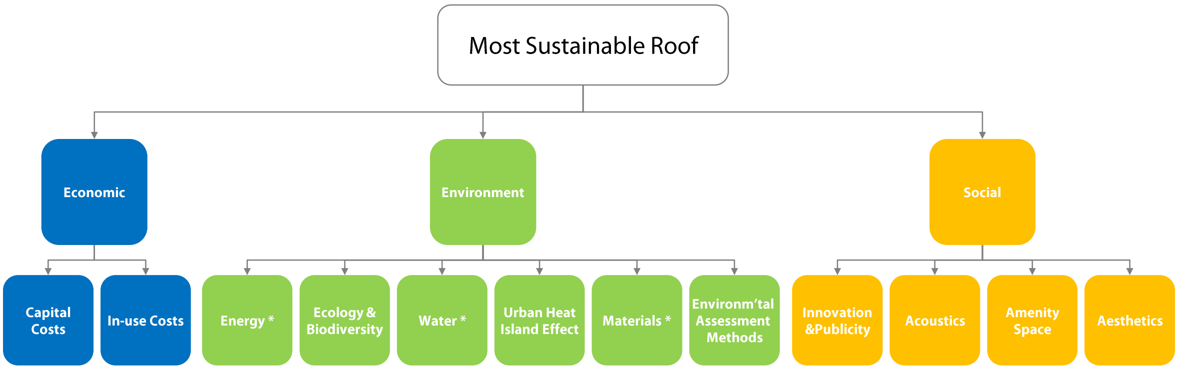


Figure 14—3 Decision tree using attributes identified from the literature review[10]

[10] * denotes that there is further levels of the decision tree that are shown in the following images

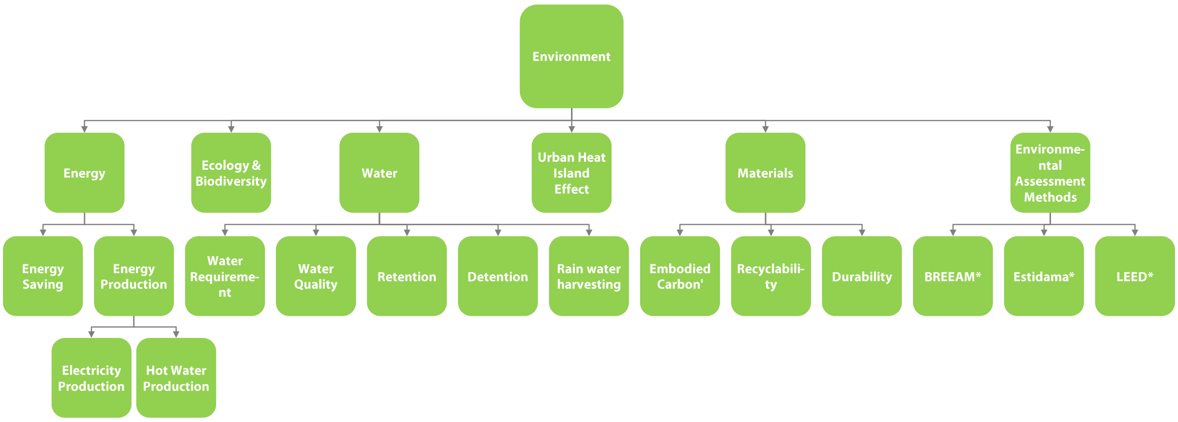
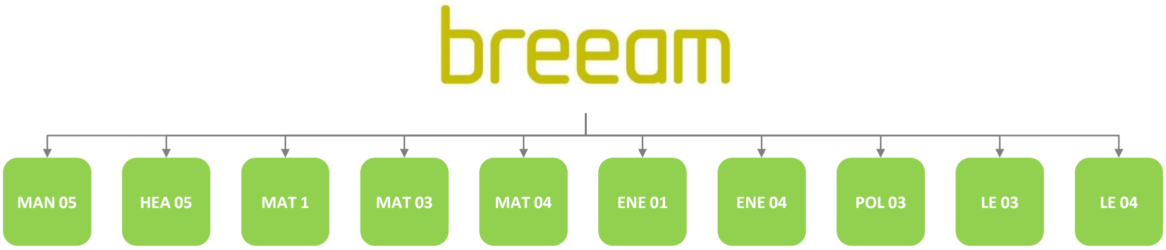


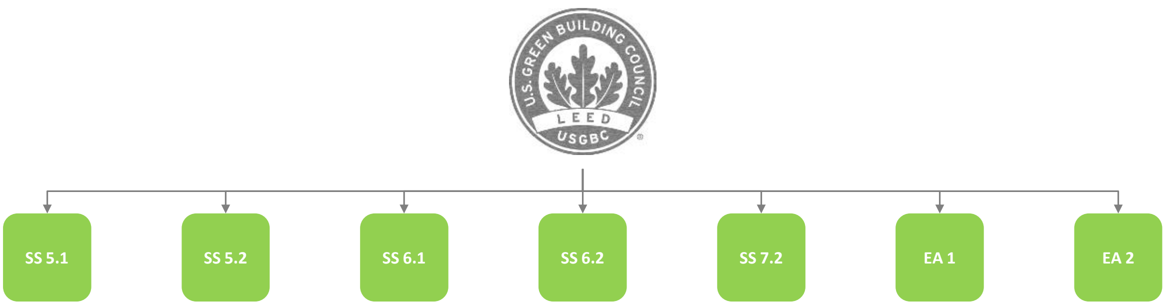
Figure 14—4 Expanded environmental decision attributes[11]



Key

MAN 05	Life cycle cost and service life planning	ENE 01	Reduction of CO2 Emissions
HEA 05	Accoustic Performance	ENE 04	Low and zero carbon technologies
MAT 01	Materials	POL 03	Surface water runoff
MAT 03	Responsible Sourcing of Materials	LE 03	Mitigating ecological impact
MAT 04	Insulation	LE 04	Enhancing site ecology

Figure 14—5 BREEAM decision attributes relating to roofs

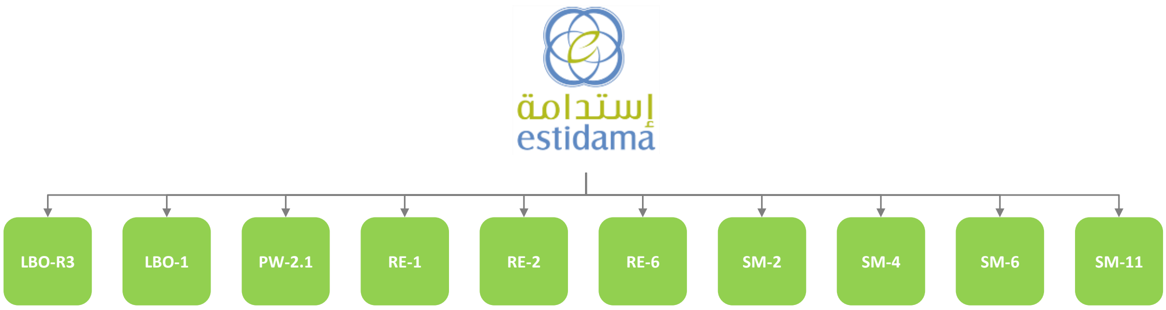


Key

SS5.1	Site Development - Protect or Restore Habitat	SS7.2	Heat Island Effect - Roof
SS5.2	Site Development - Maximise open space	EA 1	Optimise Energy Performance
SS6.1	Stormwater Design - Quantity Control	EA2	On-site Renewable Energy
SS6.2	Stormwater Design - Quality Control		

Figure 14—6 LEED decision attributes relating to roofs

[11] note that EAMs are covered in the following images



Key

LBO-R3	Outdoor Thermal Comfort Strategy
LBO-1	Outdoor Thermal Comfort
PW-2.1	Exterior Water Use Reduction
RE-1	Improved Energy Performance
RE-2	Cool Building Strategies
RE-6	Renewable Energy
SM-2	Design for materials reduction
SM-4	Design for disassembly
SM-6	Design for durability
SM-11	Rapidly Renewable Materials

Figure 14—7 Estidama decision attributes relating to roofs

Table 14—1 states the objectives for each attribute, the variable used to assess each attribute and the rating type, along with the method of assigning a value to represent the performance of different roofs.

Table 14—1 Decision objectives and attributes and the associated variable denoting the method of measurement

Category	Objective	Attribute	Variable	Rating Type	Modelling / Rules of Thumb / Existing Research
Economics	To minimise the capital cost of the roof	Capital Cost	£	Value Function	Input Roof Costs
	To minimise operational costs of the roof	In-Use Cost	£	Value Function	Calculate based on assumptions
Social	To maximise the publicity of the roof through demonstrating innovation	Innovation and Publicity	Consultant score on a scale of 0 to 10	Direct Rating	User input
	To maximise the aesthetic appeal of the roof	Aesthetics	Stakeholder weighted average score for option	Direct Rating	User input
	To maximise accessible space at roof level	Amenity Space	m2 of accessible space	Value Function	Rules of Thumb
	To maximise acoustic comfort	Acoustics	Score given by consultant	Direct rating	User input
Environment	To maximise hot water production	Hot Water Production	kWh/annum	Value Function	Modelling / Rules of Thumb
	To maximise electricity production	Electricity Production	kWh/annum	Value Function	Modelling / Rules of Thumb
	To minimise energy use	Energy Use	kWh/annum	Value Function	Modelling

Category	Objective	Attribute	Variable	Rating Type	Modelling / Rules of Thumb / Existing Research
	To maximise ecology and biodiversity	Ecology and Biodiversity	Area weighted species index	Value Function	Utilise Existing Research
	To maximise water quality	Water Quality	% removal of TSS	Value Function	Utilise Existing Research
	To maximise retention	Retention	Annual Retention of Rainfall (%)	Value Function	Modelling / Rules of Thumb
	To maximise detention	Detention	Average lag for rainfall events	Value Function	Utilise Existing Research
	To maximise rainwater harvesting	Rainwater Harvesting	m3 of water per annum	Value Function	Modelling / Rules of Thumb
	To minimise watering requirement	Watering Requirement	m3 of water required per m2	Value Function	Modelling / Rules of Thumb
	To minimise the urban heat island effect	Urban Heat Island Effect	Roof Temperature (annual degree hours above 20C)	Value Function	Modelling
	To minimise embodied carbon	Embodied Carbon	kg of embodied CO_2 per m2	Value Function	Utilise Existing Research
	To maximise recyclability	Recyclability	% recyclable	Value Function	Utilise Existing Research
	To maximise life span	Durability / Life Span	Warrantee in years	Value Function	Utilise Existing Research
	To maximise the BREEAM credits relating to roofs	BREEAM	Various	Value Function	Varies dependent on credit allocation
	To maximise the LEED credits relating to roofs	LEED	Various	Value Function	Varies dependent on credit allocation
	To maximise the Estidama credits relating to roofs	Estidama	Various	Value Function	Varies dependent on credit allocation

It should be noted that whilst this provides a significant list of typically considered roof attributes defined in the literature. Other decision support approaches including those of Grant (2007) and Nelms et al. (2005, 2007) have undertaken a similar approach. In the development of this set of attributes, the work of Nelms et al. (2005, 2007) was considered closely and she based her list on the work of Becker (2002). This was instead of using the categorisations of Technical, Economic, Environmental, Quality, Knowledge Management, Time, and Business Performance, which seemed somewhat arbitrary. Additionally, it was considered that elements of technical performance would not be of interest to stakeholders and thus ruled out of the assessment. If an option cannot perform from a technical perspective, then it should be ruled out by the design team as it is not a feasible option.

Ideally, both the approaches outlined in Part 1 and Part 2 of the thesis would be used to inform sustainable and high value roof selection. However, each can be used in isolation if required; Part 1 for better integrating stakeholder understanding into the development of sustainability and value objectives; Part 2 to inform sustainable roof selection through a list of attributes related to sustainability that are influenced by roof selection.

If both parts are undertaken, it is considered that the approaches outlined in Part 1 are done prior to application of the roof decision support tool in Part 2. The reason for this is that Part 1 provides an approach for eliciting the key sustainability and value criteria at a project level. If Part 1 approaches are undertaken then the resulting output will be a set of sustainability and value themes as defined for that particular project context by the project stakeholders. It is intended that this could be done on projects to inform the development of a sustainability and value framework for the project, which goes beyond just roof selection, but could be used as a basis for informing the development of decision making attributes for many of the component, or system selections for the project. This should consider the framing of roof objectives as means objectives to achieve fundamental strategic objectives of the project (Keeney, 1992).

In the case of this research it is intended that the project wide sustainability and value objectives identified through the application of approaches in Part 1 should then feed into the selection of roof attributes, which is part of the process outlined in the DST tool developed in Part 2 of the research. This is demonstrated in Figure 14—8.

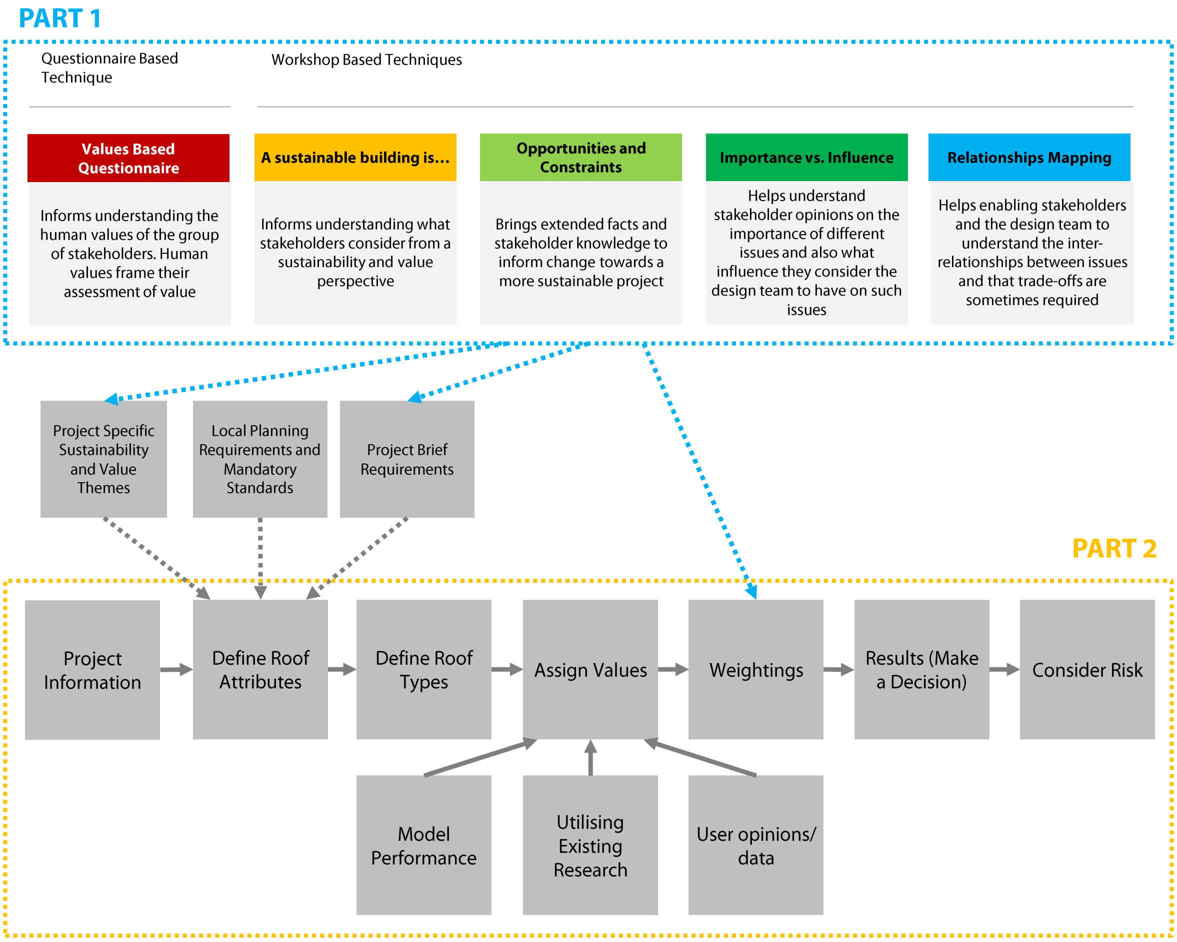


Figure 14—8 Relationship between Part 1 and Part 2

Figure 14—8 shows possible information that could feed into the selection of roof attributes in the application of the Roof DST. If Part 1 approaches have been applied the approach would consider how the list of roof attributes relate to the sustainability and value themes identified for the project at the "define roof attributes" stage.

Figure 14—8 also considers the *"project brief requirements*", as it is understood that project *"sustainability and value themes"* as defined by techniques such as those developed in Part 1 of the thesis may not be available. This could involve reviewing the project brief for requirements related to the performance of roofs, as considered in the Action Research Case Study 2A in Section 11.4.1. Additionally, criteria may also consider *"local planning requirements and mandatory standards",* also shown in Figure 14—8. Whilst, this isn't the focus of this work, roofs not meeting these standards should be ruled out prior to any further analysis.

However, in all cases the approach advocates a value focused thinking approach linking roof objectives to higher level strategic project objectives. Figure 14—9 considers the relationships between the roof objectives and the strategic project objectives based on the value focused thinking framework (Keeney 1992). It is intended that the techniques developed and tested through Part 1 of the thesis will be implemented to define the strategic project objectives *("project specific sustainability and value themes"* as shown in Figure 14—8). The roof choices, whilst representing a subset of the overall project choices, should align with these.

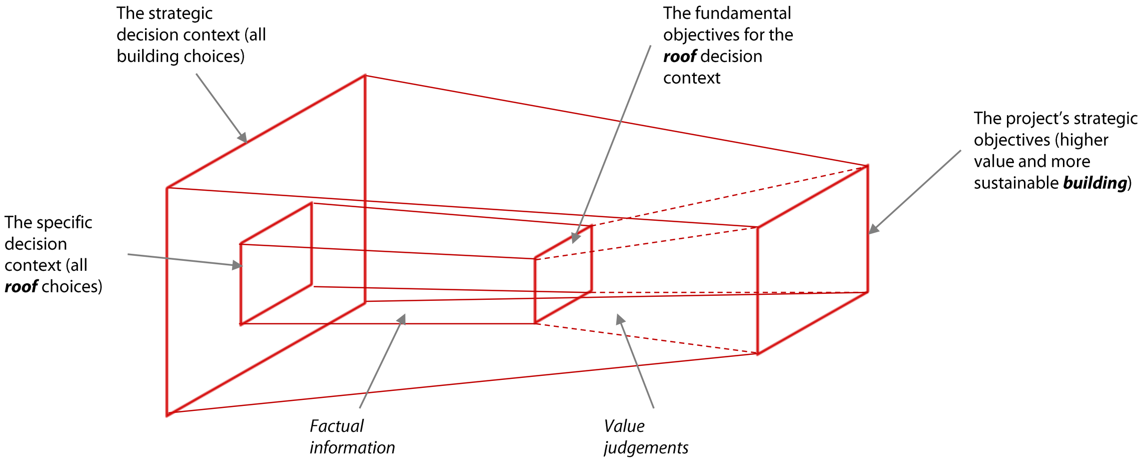


Figure 14—9 Relationships between roof objectives and strategic project objectives[12]

As described in the previous section the attributes in the value tree are selectable in the DST. These provide a basis and a set of prompts for what the roof typically influences and they can be selected accordingly from the 'user form' as shown in Figure 14—10. This checklist provides a useful set of roof considerations, which may otherwise be forgotten by the stakeholders. A study summarising three empirical studies showed that participants consistently emitted nearly half the objectives that they considered important, the results were then replicated in a real-world case study of strategic decision making (Bond et al., 2008). In a follow up study Bond et al. (2010) looked into reasons for this and ways in which more comprehensive lists of objectives could be developed. A variety of interventions were tested which included, the provision of sample objectives, organisation of objectives by category, and direct challenges to do better. Organisation of objectives by category and prompts both improved the elicitation of objectives. Providing a sample set of objectives did not improve the generation process.

[12] based on Keeney (1992) VFT framework

Therefore, it is proposed that stakeholder considerations for sustainability are elicited unprompted but structured by themes as set out in the previous part of this thesis and elicited through stakeholder engagement techniques such as those outlined in Part 1 of the thesis. The list then acts as a final checklist of considerations, also highlighting roof related criteria from the environmental systems of BREEAM, LEED and Estidama.

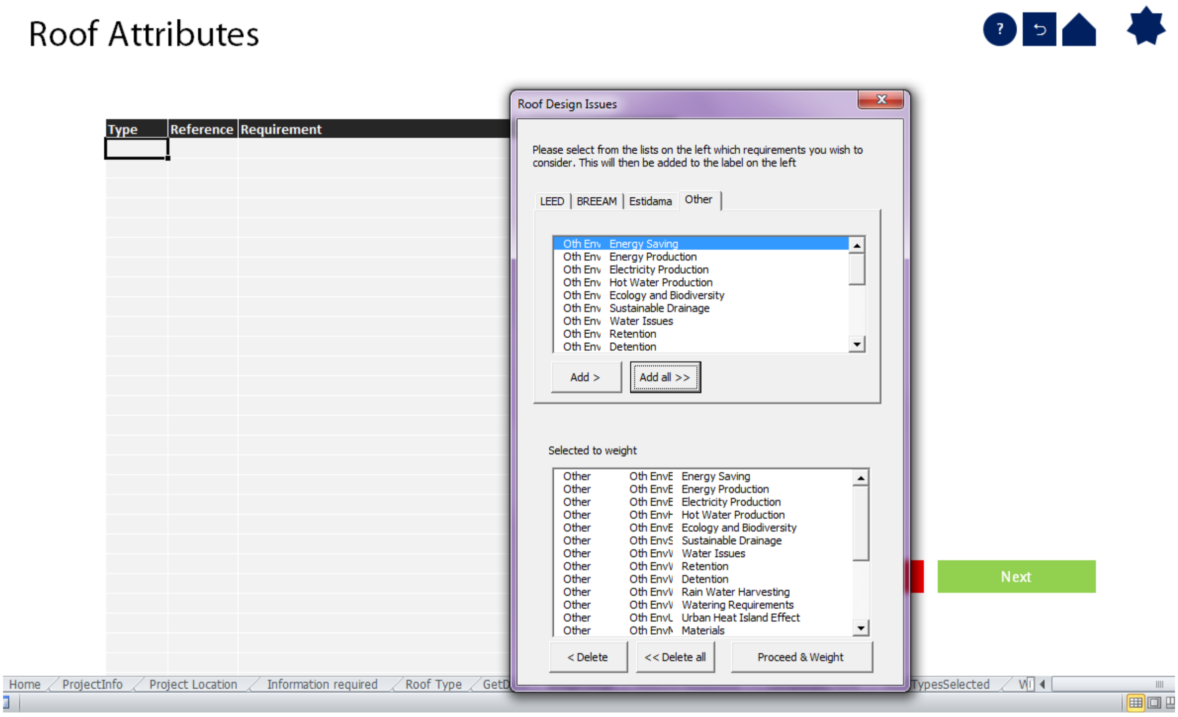
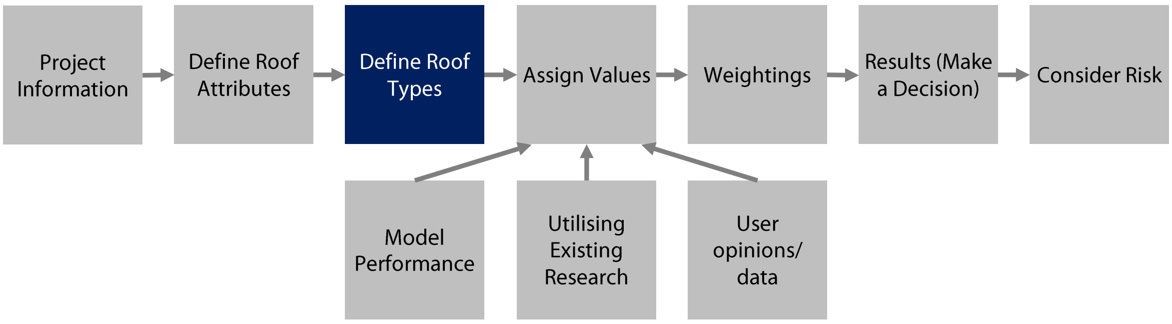


Figure 14—10 Roof attributes selection page

In addition to the standardised criteria the user can also add other criteria and classify them under environmental, social or financial. These are then added to the decision tree. For additional attributes it should be noted that the decision maker is required to score all the different roof options manually, and thus this can significantly add to the time required to undertake the decision analysis. However, it is considered important to give the user this flexibility and to consider aspects that are relevant to the local context and reflect the needs of the project's stakeholders.

14.2.3 Define roof types



Considering all different roof options would be impossible and unwieldy. There are so many different roofing products available that gaining a comprehensive database of options for people to select between, along with reliable data on the performance of the different options in aspects relating to sustainability would be many lifetimes worth of work. However, a set of generic roof systems have been defined for consideration in the tool and are shown in Figure 14—11.

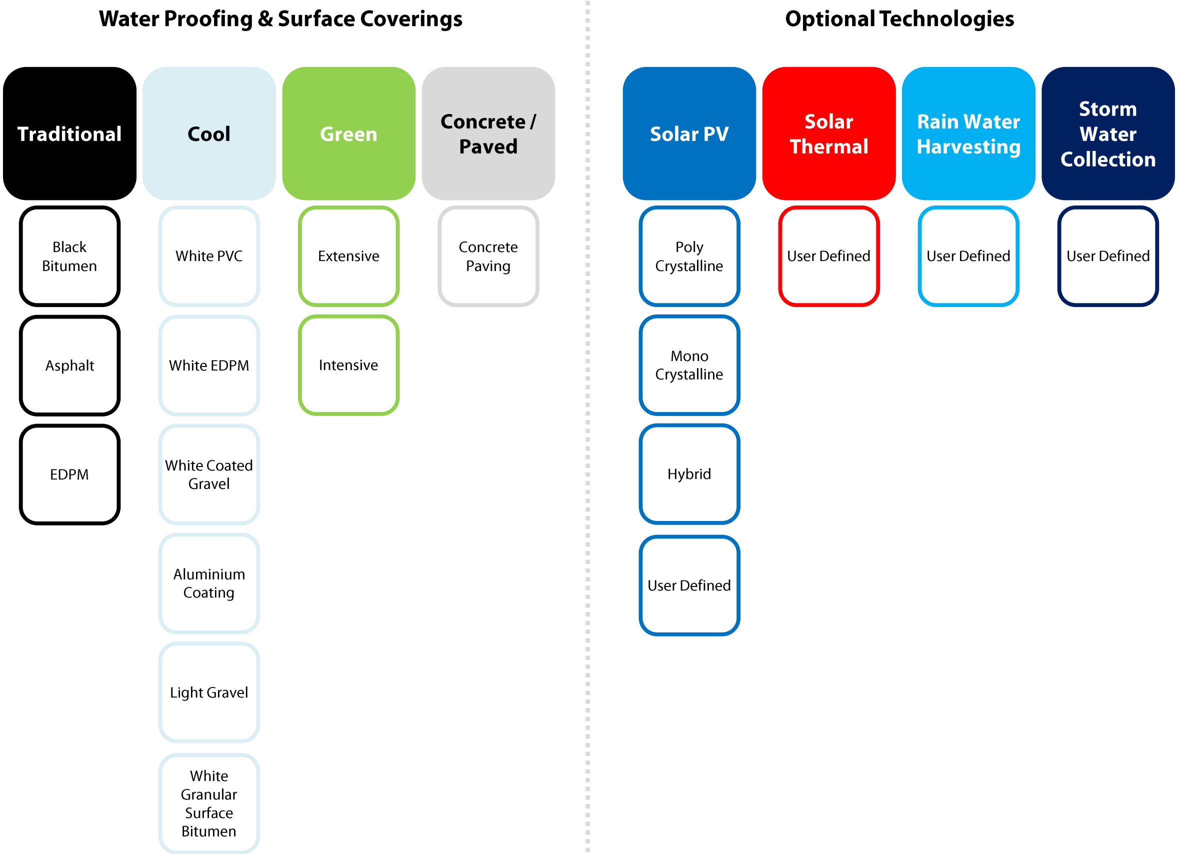


Figure 14—11 Roof options for consideration in the roof selection tool

Figure 14—11 splits the roof systems into two groups:

- **Waterproofing and Surface Coverings:** These provide waterproofing and the surface cover of the roof. They are split into four main types of 'traditional', 'cool', 'green' and 'paved'.
- **Optional Technologies:** These are optional systems that can be applied to the roof, but are not required to provide the roof's protective function. These are split into four main types of 'solar PV', 'solar thermal', 'rainwater harvesting' and 'storm water retention'.

When selecting options, the proportion of the roof area is required to be input. Additionally, for some roof systems further information is required. For example, with respect to solar PV systems, an orientation and inclination will also be required in order to calculate a realistic energy output. User defined systems also ask for additional information such as efficiencies or performance characteristics.

Roofs are assessed for the whole roof area of the building. This means the DST offers the ability to compare single roof systems against each other, or combine numerous roof systems on to a roofscape. A roofscape is comprised of all the roof types that are required for the roof, or roofs, of a building. These are referred to as either:

- ***Mono-roof:*** one waterproofing / surface covering along with a maximum of one optional technology across the roofscape
- ***Multi-roof:*** numerous roof systems and optional additions can be defined for the building's roofscape

An example of a mono-roof compared to a multi-roof is shown in Figure 14—12.

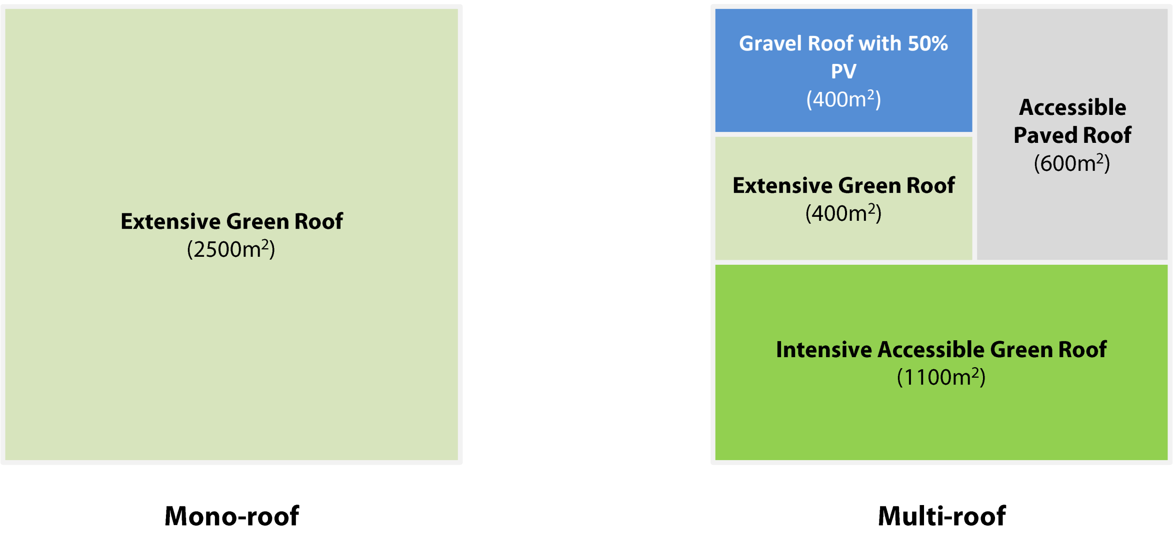


Figure 14—12 Example of a 'Mono-roof' and 'Multi-roof' construction for consideration in the roof selection tool

Selecting "multi-roof" option takes the user to the "roof builder", which essentially allows the user to select numerous roof types for installation on one roof. It should be noted that the individual areas of the multi roof must add up to the total roof area defined in the 'project information' section of the tool. This kind of roof builder, doesn't require the user to specify which roof system goes where on the roof i.e. the layout and adjacencies are not considered by the DST. The roof DST only considers the area of each roof system that makes up the entire roofscape.

However, not considering the location of different roof types does have some limitations that will have to be considered by the design team. These are discussed more in Section 14.3. It should be noted that even for the mono-roof a technology can be selected for installation on the roof, however only one roof covering and one roof technology is allowed on a ‘mono-roof’, whereas on a multi-roof as many different systems can be defined as the user wishes.

Where several roof systems are combined on a multi-roof, the scores will be taken as an area weighted average of the performance of the different options. For example, if a “white” roof was specified for 60% of the roof area and a green roof specified for 40% of the roof area then the performance would be a weighted average of the two types of roof system. As identified in the Action Research Case Study 2A in Section 11, this allows multiple systems to be combined on one roof type and the benefit of that roof as a whole to be assessed against a different combination. This expands the research on that which has preceded it (Grant 2006; McCourt 2007). Additionally, clients will often be interested in the combination of options rather than just the benefits of one roof type over another.

An example of the screens from the tool which allows the user to access the roof types are shown in Figure 14—13.

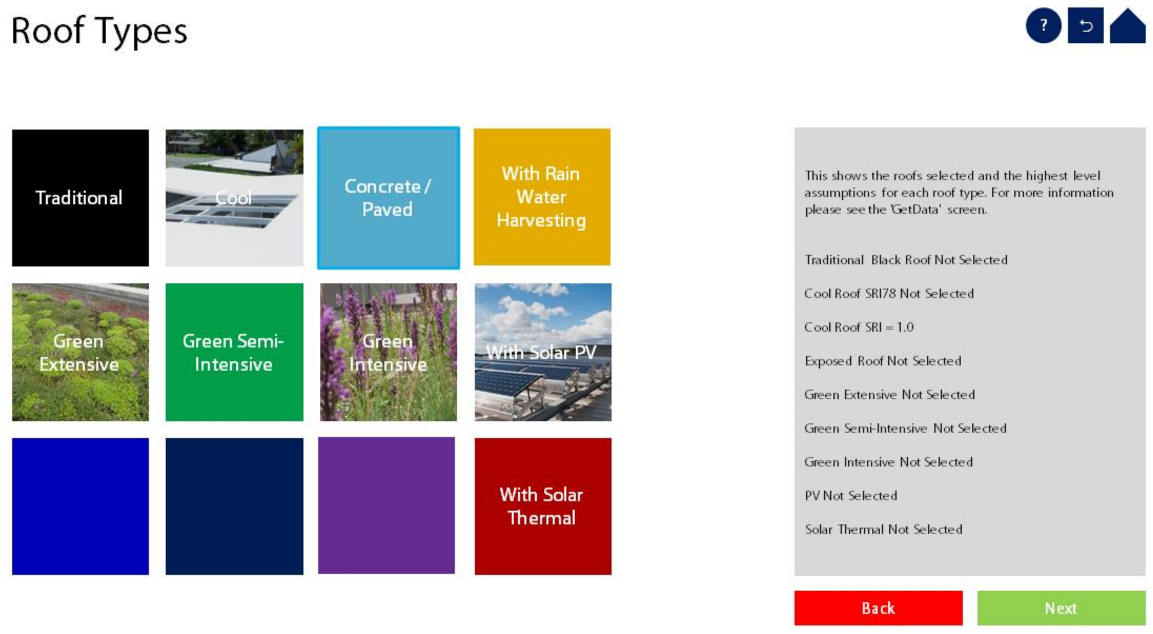


Figure 14—13 Roof types available for comparison

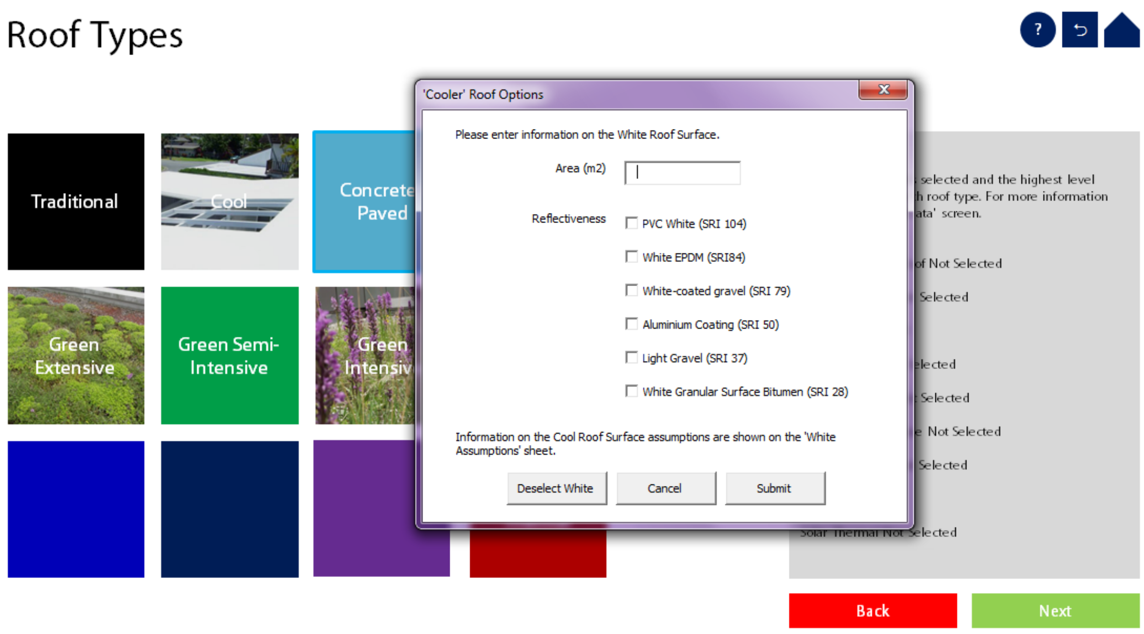
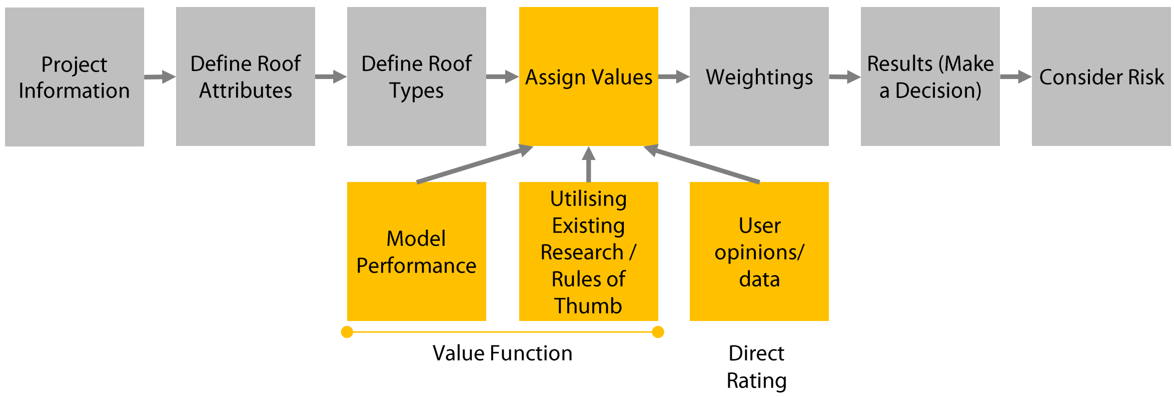


Figure 14—14 Selecting a white "cool" roof type

14.2.4 Assign values



In order to assign values to measure the performance of roof systems against each attribute, a variable has been identified to measure its performance as shown in

Table 14—1 in the Section 14.2.2.

Goodwin and Wright (2009) outlines two approaches for assigning measures to how well different options perform for a particular set of attributes. These are, (1) direct rating; and (2) value function (Figure 14—15). Both of which convert performance into a normalised value with a score between 0 and 100%. This allows performance across many different variables to be weighted and ultimately aggregated.

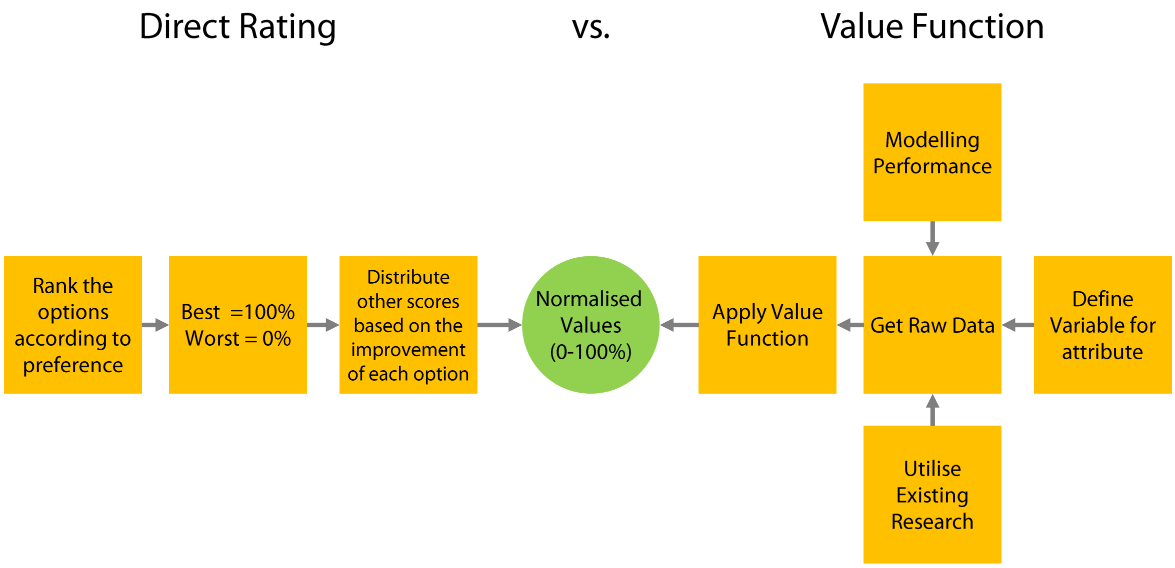


Figure 14—15 Approaches to assigning values to attributes for roof options

For attributes where it is hard to define a variable to measure the performance of roof systems or the performance is more subjective, for example attributes such as "aesthetics" and "innovation and publicity value", these are assigned a value using a direct rating for each option ideally with input from the stakeholders. The direct rating technique, first asks users to rank the options in the order of preference for that particular attribute. The best performing option is then given a score of 100% and the worst performing option a value of 0%. The remaining options are then scored proportionally on a scale between 0 and 100% based on the relative value of improvement between each options. For example, if an option performed half way between the best and worst scoring option it would be given a score of 50%.

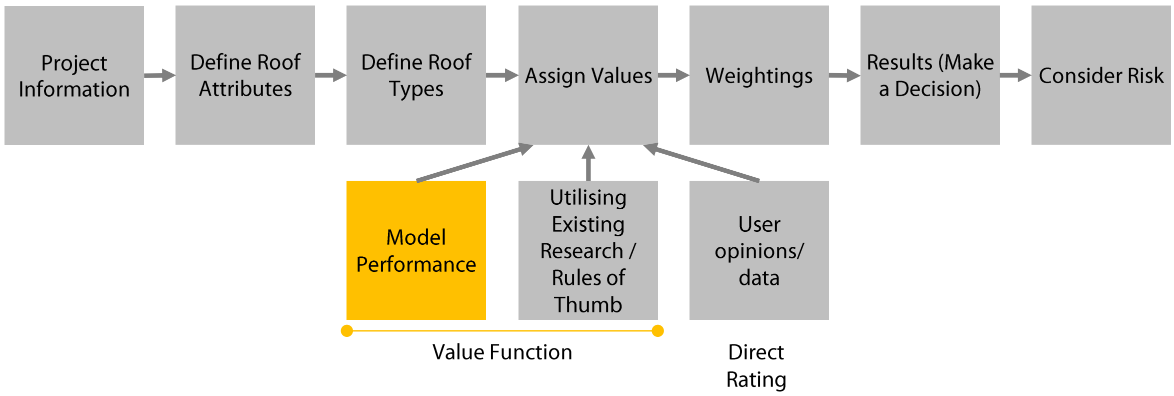
Where variables can be defined for an attribute and performance of roof options assessed in terms of that variable then a value function approach is recommended. First a variable is defined, then performance is measured against that variable. Then a value function is applied to convert the raw data into a normalised value for each option. For simplicity a linear value function, is employed by the DST. This is recognised as being a suitable simplification by Edwards and Barron (1994) and typically will not have a large impact on the outcome of the technique if improvements at either end of the scale are not more than twice as important as at the opposite end of the scale. The validity of this assumption will be dependent on the project's context. The author believes through experience that this will be true in most cases, but where it is not a more complicated non-linear value function should be used, but this would have to be entered manually into the DST.

In the past the data available to assess the performance of each roof type has been difficult to acquire. Additionally, where it has been provided, it has given little respect to the context in which it should be applied. A main contribution of this research is bringing together information from a diverse range of disciplines to quantify the performance of different roof systems. When considering the value function approach, the following methods have been used to gain the raw data required:

- **Utilising existing research (see Section 12):** this explains an approach seeking to categorise information on roof systems, so that the most appropriate research from journal papers can be used to provide the data for a context specific decision rapidly.
- **Model performance (Section 13):** this explains the modelling approach that has been set up to calculate the performance of different systems where possible. This covers the performance of more traditional roofing options and also some types of green roofs. This is the preferred approach for aspects of performance that are currently well enough understood to have formulae and algorithms that can be used to calculate context specific performance.

Once this data is in the DST from either modelled performance or from reference data from existing research it can be converted into normalised values. An example of the conversion of raw data to normalised values on a scale of 0-100% is shown in the case study below.

14.2.4.1 Importing modelled data into the DST



After going through the stages of the DST and providing information on the project context, such as location, selecting the attributes and roof options of interest, the user is then prompted to “get-data”, which asks the tool to bring together all the information from applicable past model runs, into the roof selection tool. The standardised structure allows this to be done automatically. The tool works in a Microsoft Excel spreadsheet, with Visual Basic for Applications (VBA) code defined to get the most appropriate “.csv” output files from the building simulation software and quickly compile the most relevant results for the user input location, roof attributes and roof types. These are then brought into the spreadsheet as raw data, which are then summarised statistically by the tool. For example, the tool then calculates aspects such as monthly average values and annual averages, sums, maximums, minimums, which provide the singular annual values which go into the decision making framework.

Microsoft Excel and VBA were chosen as the platform and method to do this, as Excel is a program that is commonly used in the industry and something which most professionals would be comfortable using. Additionally, it was considered that professionals may want to interrogate the data and information on which the decision values would be calculated as a sanity check that the correct information is being used by the decision tool. This also improves transparency.

The raw results are filed in individual tabs for each roof attribute selected and the raw results contain hourly information for each roof type. This means that the user or design team can go in and compare how each roof is performing at any given time. Additionally, it provides the data on which to calculate the summary values for the performance of each roof type. It also provides an audit trail of detailed information which can be referred back to at any point.

Whilst it is considered important to be able to allow the user of the tool to also see the raw performance of the different options, again such large amounts of raw information can be overwhelming to the analyst. Therefore an interactive dashboard to show this information was developed (Figure 14—16). This allows the user to select a time period that they are interested in and the roof attributes that they are interested in viewing and show plots of the performance of options. This can be summarised in many ways to instantly see maximum, minimum, average and total values on an hourly, daily, or monthly basis. Additionally, up to 4 graphs showing different characteristics can be seen at once, allowing the user to compare across different attributes in a simple and easy to use way. As it is the annual performance that we are most interested in, annual sums or averages of data are usually the singular value that is taken by the DST to represent performance. This is brought automatically into the DST.

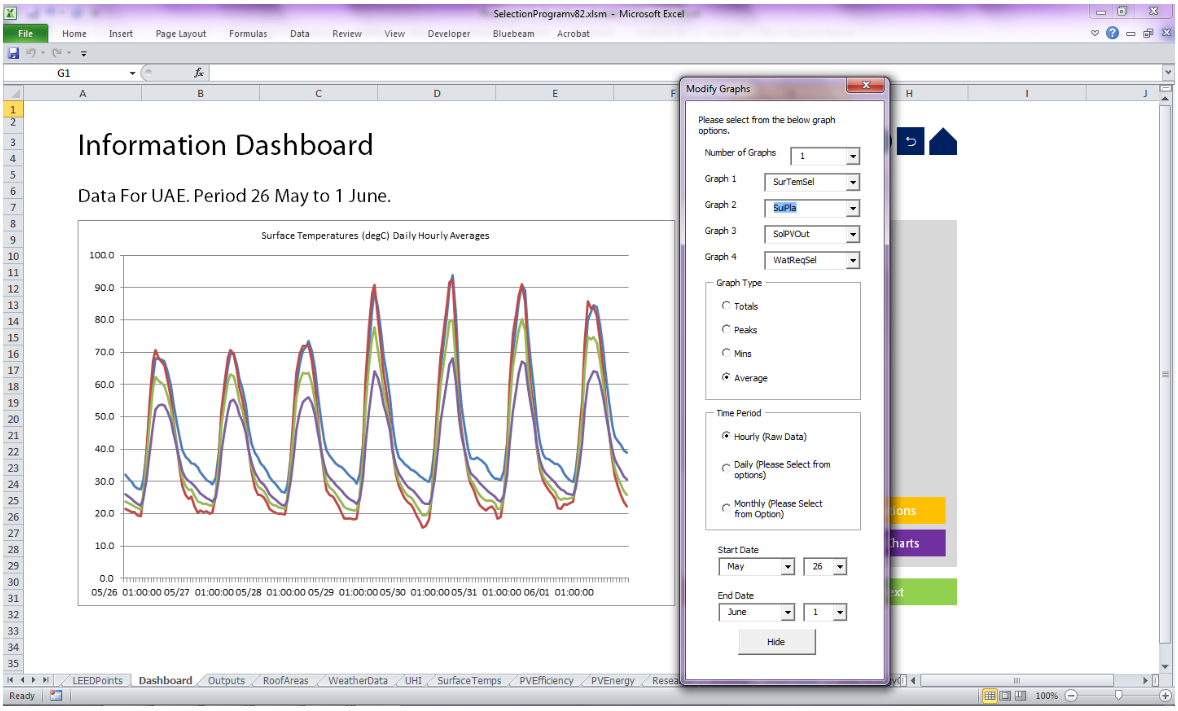
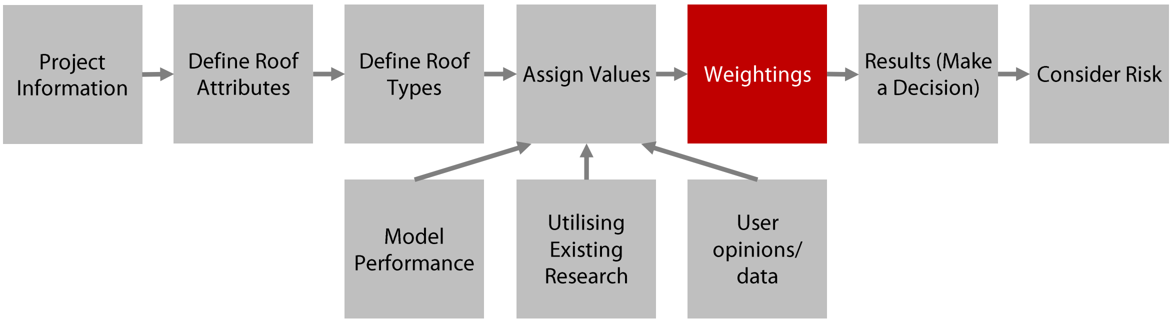


Figure 14—16 Example information dashboard from the roof decision support tool

14.2.5 Weightings

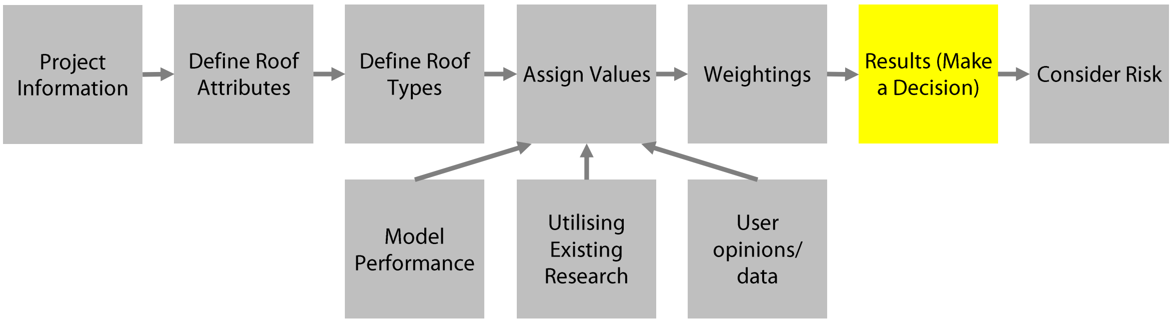


Unlike typical assessment systems where the weighting is already specified for the numerous decision attributes, the DST aims to take on board the opinions of the projects stakeholders in order to inform the decision. The weightings for the different categories outlined in the tool can therefore consider the preferences of the stakeholders. This takes a more value based approach to decision making, understanding the considerations which are classed as important to those that will be effected by the decision.

The only exception to this is when considering the weightings for roof related credits under the environmental assessment methods of BREEAM, LEED and Estidama. For the roof related credits defined for each assessment system they will be weighted according to their value given by the assessment system. Thus the project stakeholder will not be able to change the weightings of the Environmental assessment methods sub-attributes. However the weighting given to represent the importance of achieving any Environmental Assessment Methods as a whole can be defined by the stakeholders and input into the DST.

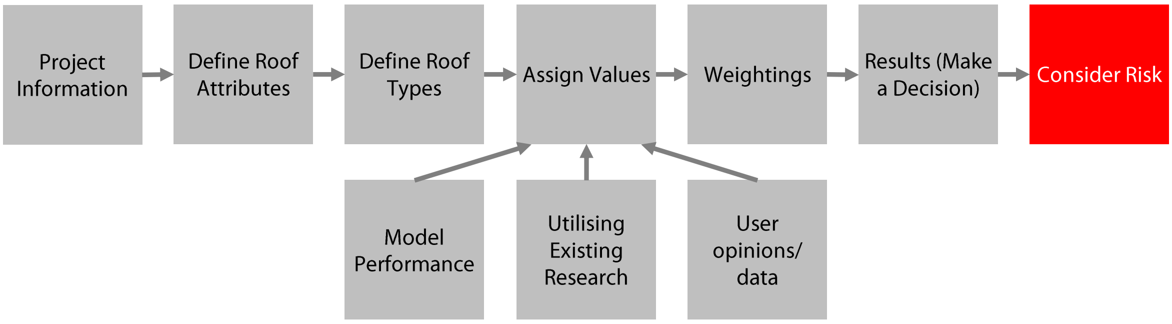
Weighting is considered by Goodwin and Wright (2009) and Keeney (1992) as the most commonly made mistake with respect to decision making. These mistakes are highlighted in the critique of McCourt (2007) in Section 3.7.3 and involves users weighting the importance of the attributes without considering the performance of the various options on those attributes. Thus a swing of £1 can be weighted as much more important that large increases in performance. To avoid this issue, the user is asked to consider how much they value the swing in performance between the best and worst performing option. This is illustrated through the case study in Section 14.3.5.

14.2.6 Results (make a decision)



The next stage involves aggregating the normalised scores. This is done using a simple additive model, which multiplies the dimensionless score for each attribute by the weighting and then adds together all the weighted scores for individual attributes for each roof option. This then becomes the aggregated normalised benefits, which are used to assess the value of the options. This will either include or not include the score relating to costs, depending on whether the user of the decision tool has given this a weight or not.

14.2.7 Consider risk



There are two options that have been incorporated into the decision support tool to assess risk. The first of which is to undertake sensitivity analysis. This allows the decision maker / tool user to understand how robust the option is to changes in the weightings used in the analysis. For example, it allows the exploration of "what if" scenarios, which could include what if the weighting of some of the attributes were to change. This is possible for changing weightings, and the results are automatically calculated. An example on the sensitivity analysis is shown in the case study in Section 14.3.7.

Another element of risk with respect to the selection of green roofs is whether or not they will be suitable for the climate type or region in question. To understand the risk of locating a green roof in a climate type, a method of understanding whether green roofs has been applied in that region or climate type previously has been developed. It is argued that if green roofs are common in a project's location or climate type, then the risk of installing a green roof is reduced.

However, to do this an accessible green roof database of global projects was required. The most comprehensive accessible database of global green roof projects was found to be the *'International Green Roof and Green Wall Database'* (greenroofs.com, 2013) containing approximately 1,400 green roof projects. This database contained fields on the following (Velazquez, 2005):

- Project name;
- Location (city; state/province; country; region);
- Project year (year completed or click the current box);
- Building Type: (i.e. commercial, municipal, single family residential, multi-family residential, industrial, multi-use, corporate, educational, park, religious, aviation, aboveground parking garage, at-grade/underground parking garage, or other);
- Green roof type (i.e. extensive, intensive, semi-extensive, semi-intensive, extensive & intensive); green roof system (i.e. single source provider, custom, other);
- Construction type (i.e. new or retrofit);
- Test/research (yes or no);
- Designer/company name;
- Roof:
    - Roof size (less than, equal to, greater than);
    - Roof slope (less than, equal to, greater than);
- Accessibility: Accessible or inaccessible; public or private;
- Keywords coming soon[13]: (energy, heat island, temperature, stormwater, vegetation, growth media, wildlife, biodiversity, health therapy, grant, incentive, award, LEED, BREEAM, etc.).

This is an extremely useful database providing a rich dataset on global green roofs. However, one field which was considered missing from this database, which would be useful when assessing project's risk, was the climate type. For this reason, a simple tool was developed by the author to categorise the most probable climate type for each project based on the project's location. This was utilised to find the nearest weather file to that particular green roof location and data from the weather file was used to categorise the green roof according to the Koppen Geiger Climate Type. Additionally, as weather files are also tagged with other pieces of information such as heating and cooling degree days these were also added to the database. This was done through modifying the open source code utilised in the VBA programme, Weather File Finder (Bull, 2012).

[13] Not yet a field in the database, but 'coming soon'

This data was then uploaded to a Google Fusion Table which was used to plot the maps spatially, and also sort and assess the climate types of the different green roofs. A plot of the international green roof locations is shown in Figure 14—17. This interface works in the same way as Google maps and allows the user to zoom into particular locations. Additionally, upon clicking any of the green roof points, more information regarding the green roof is shown. Additionally, information on the maps can be sorted accordingly, so all roofs that are currently being researched could be shown and the rest hidden.

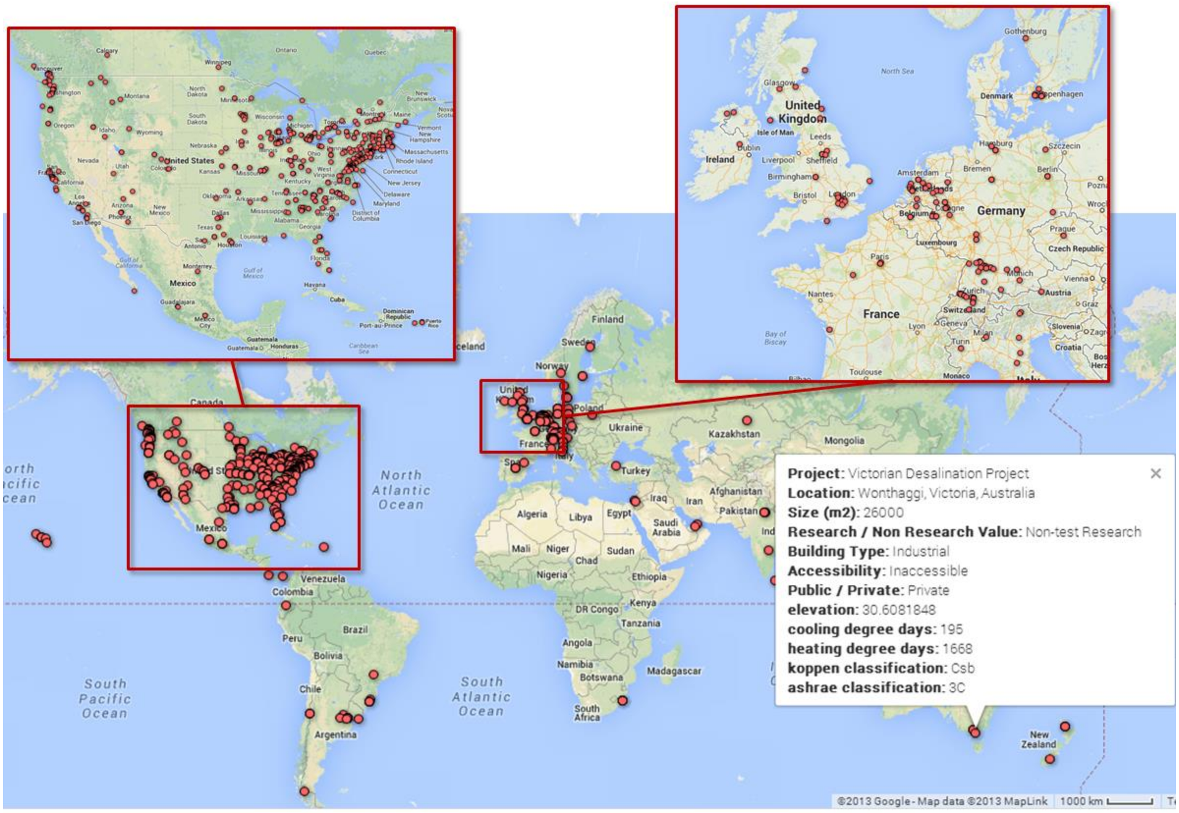


Figure 14—17 Global green roof locations plotted utilising Google fusion tables

Additionally, utilising the google fusion labs 'network graph' option, one can start to see relationships between climate types and the area of green roofs of certain types, represented by the weight of the lines (see Figure 14—18). The size of the nodes represents the number of roofs of that particular type (yellow nodes), or in that particular climate type (blue nodes). This shows, for example, a strong precedence of extensive green roofs in Dfa, Cfb and Cfa climates. Whilst there are some examples of Extensive roofs in Bsh, Bwh and BSk climates, there is less precedence for it in such climates. This would represent that installing a project in such regions may be more risky.

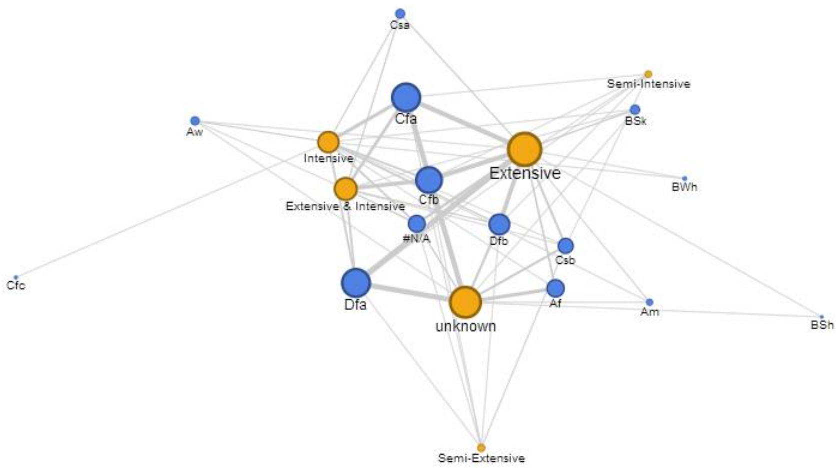


Figure 14—18 Relationships between green roofs installed in different climate types [14]

The risk can also be assessed by looking at heating and cooling degree days and comparing it to a particular project location. As can be seen here there are significantly fewer green roofs at the extremes of these scales, and thus this could represent higher project risk if they are installed in such locations.

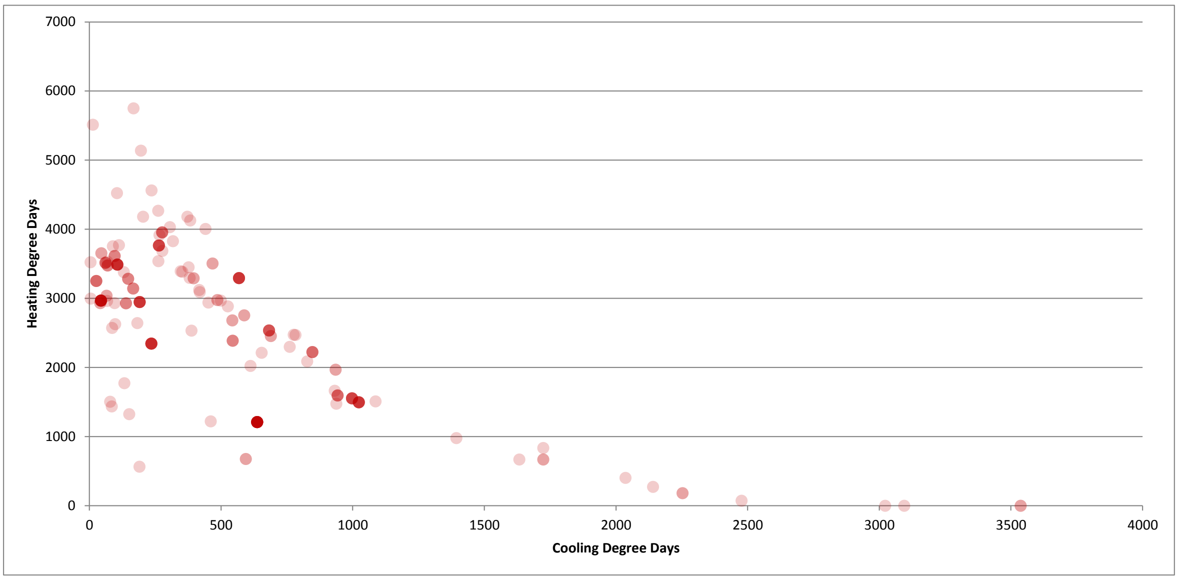


Figure 14—19 Green roofs plotted against heating and cooling degree days[15]

[14] Yellow nodes represent the area of each type of green roofs (their size relates to the area of the node). The area of green roofs in each climate types is represented by the blue nodes. The weight of the lines represents the area of each type of green roofs in a particular climate type

[15] Darker points represent numerous occurrences of the same values

Whilst this does not give an explicit value for risk it is hoped that this helps inform the decision maker and gives enough guidance to be able to assess the risk of different green roof options for their particular context. It also provides suitable context specific case study data to inform design. If risk is something of concern to the stakeholders it could be placed as an additional attribute when defining different attributes and techniques, such as the one highlighted above used to inform a direct value rating for each roof system type. This could then be incorporated formally into the decision making process through the DST.

14.3 Case study results

In order to demonstrate the overarching methodology and also the functionality of the tool, the process is followed for a hypothetical decision, utilising data from the tool. However, the example will be based upon a piece of work done by the researcher looking to inform the design and selection of a roof for a university building in Case Study 1B from Section 8. The original piece of work was conducted prior to having fully developed the decision support tool, so the tool could not be effectively implemented on this project at the time.

The example (relating to Case Study 1B) shows a selection of attributes and how the sustainability of the roof classed as the environmental and social value, along with the economic costs can be rapidly calculated for many roof options. For each step of the method outlined in Figure 14—1, the information to be input and the process is described for the case study example, in order to demonstrate the use of the tool.

14.3.1 Project information

The project information is entered below for the University Building, which is shown in Figure 14—20. This accounts for the roof area and an approximate gross floor area based on the number of stories of the building.

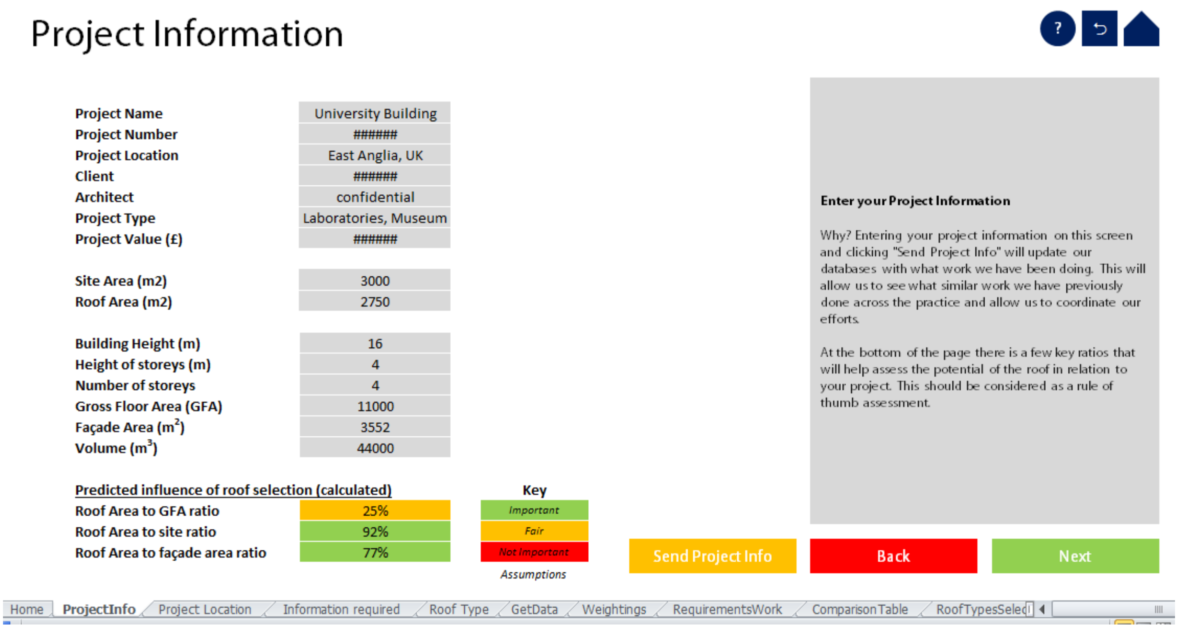


Figure 14—20 Project Information for case study project

Due to the large footprint of the building (and therefore roof area) in relation to the plot (92%) and a moderate roof area to gross floor area ratio (25%) the roof was shown to have a significant impact on the project. Therefore, the roof decision has been classed as worthy of further consideration.

The project location was selected to be South East, UK and the nearest weather file was calculated to be London Gatwick using the weather file finder tool (Bull 2012). Therefore this is the weather data that is used for the context specific pieces of the analysis that are run in Energy Plus. The rainfall data is not normally included in a weather file for building simulation modelling and therefore, weather data was input in the roof selection tool from the met office website. A macro in the tool converted 30 years of rainfall data into an average year and monthly values were calculated for Cambridge. These were then used to inform rule of thumb calculations that were also automatically undertaken in the tool.

14.3.2 Define roof attributes

A stakeholder engagement workshop was conducted to try to understand what represented a high value and sustainable project. This brought together representatives from many stakeholder groups in an attempt to define the sustainability focus areas for the project context. This focused on the project as a whole to avoid sub optimisation. The workshop is previously described in Case Study 1B (Section 8).

An example of how this may be done by the user of the decision tool is shown in Figure 14—21. This shows the sustainability and value themes identified in the research from Part 1 in Case Study 1B on the left of the Figure.

The right of the figure shows some of the sustainability and value themes, as defined for roofs, categorised under the three areas of sustainability. It is intended that the roof decision maker could utilise the output of Part 1 when selecting the roof attributes for consideration in the Roof DST developed through Part 2 of the research. This would link the selection of roofs with the sustainability and value objectives of the project as a whole. Thus by progressing through the various stages of the approach to roof selection incorporated in the DST, how the various roof options assessed are contributing to project wide sustainability objectives will be demonstrated, through quantitative and rigorous information.

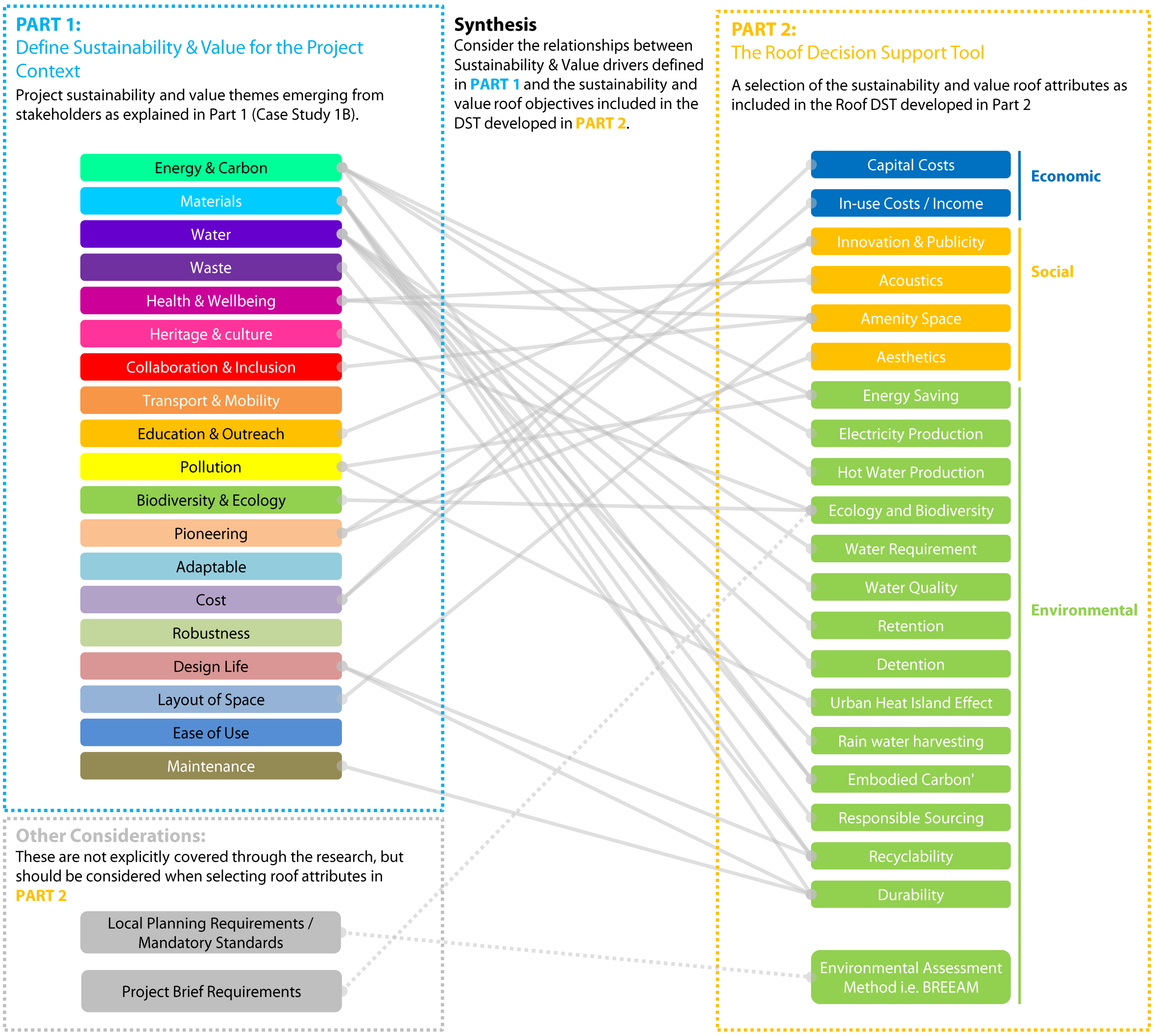


Figure 14—21 Synthesis of Part 1 and Part 2 of the research

What also requires consideration are any context specific policies, planning requirements, brief requirements that are related to the roof. These should be assessed and if any particular option does not comply with these requirements, then it should be discounted from the decision making process.

Whilst considerations relating to local planning requirements and mandatory standards have not been considered significantly through the course of this research, they should also be considered when selecting the roof attributes for decision making. These should also be considered in relation to the project brief requirements if there is a developed project brief. An example of utilising brief requirements to inform the roof selection is shown in Case Study 2A in Part 2 of the research.

Whilst it is accepted that this list of roof related decision attributes as outlined in Part 2 is unlikely to be complete, it is a large and comprehensive list that goes beyond that of any research that has proceeded it. Additionally, the prototype Roof DST also allows for roof attributes that are not currently in the list to be added and scored manually by the users utilising a direct rating method.

Once the roof attributes have been defined, the user of the Roof DST can then proceed through the stages of the tool outlined in Figure 14—1 in Section 14.2.

This shows that key considerations were Energy & Carbon, Materials, Water and Biodiversity & Ecology. Wider sustainability considerations were also considered, however, many of these may typically be considered outside the scope of influence of the roof. Such considerations include, *'Health and Wellbeing'*, *'Collaboration and Inclusion'* and *'Education and Outreach'*. These could be specifically added if considered to be relevant to the roof selection. For example, an accessible green roof / court yard, could for example have some collaboration value if used as amenity space and could allow activities to be hosted on the roof if designed appropriately. Additionally, in such as case it may also have some "Health and Wellbeing" benefits. This was considered to be covered by considering the attribute "Amenity Space". Additionally there were numerous comments relating to the need for the building to be pioneering, adaptable and cost effective with a good design life. These were covered in attributes described as "Innovation and Publicity" and "Cost". Additionally, in-use costs were not considered in the analysis, as this would have been classed as double counting as many of the factors used to determine in-use costs are variables such as 'Durability" (and the associated need for replacement for shorter life spans), "energy savings" and "energy production" (and the associated cost benefits of offset energy costs and Feed-in-Tariff incomes). Thus in-use cost is removed here. However, this could be calculated if required upon the decision user placing additional information and assumptions into the DST. In summary, the following attributes were considered:

- Capital Costs
- Energy Savings
- Energy Production
    - Electricity Production
    - Hot Water Production
- Ecology and Biodiversity
- Water
    - Water Retention
    - Rain Water Harvesting
- Urban Heat Island Effect
- Materials
    - Embodied Carbon
    - Durability
    - Structural Loading
- Innovation and Publicity
- Amenity Space

- Aesthetics

14.3.3 Define roof types

A series of roofscapes were defined for the case study project, these included a range of ‘mono-roofs’ and ‘multi-roofs’. The range of roofscapes were selected based upon the attributes defined as being important. The total number of roofscapes picked for the analysis was 11, however, this could be rapidly increased or decreased, from the palette of roof options included in the interface. The roofscapes are explained in more depth in Table 14—2. Also upon defining the roof types of interest for the decision, it is possible to change the areas of the different roof types or add more at any stage during the decision making process. Thus new alternatives can emerge and this is automatically reflected in the DST.

All roof types were considered to be located on a 8m x 6m roof as shown in Figure 13—1. However, all results were factored up to understand the impact they would have for a roof the size of the case study project of 2750m^2. This has limitations that should be addressed through future work.

Table 14—2 Roofscapes considered in the decision analysis

Roof Reference	Roof Type	Description
Mono-1	Extensive Sedum	Extensive sedum with 100mm substrate depth
Mono-2	High Albedo White PVC	Solar reflectance index of 104
Mono-3	Black Bitumen	Black bitumen roofing felt
Mono-4	Intensive Green Roof	250mm depth
Mono-5	High Albedo White PVC Roof with Hybrid PV	White PVC membrane with 1100m^2 of Hybrid PV (40% of roof area)
Mono-6	Gravel (50mm depth)	Lightweight gravel
Multi-7	White Concrete Paving Intensive Green Roof White EPDM with Mono-Crystalline PV	Accessible concrete paving - 825m^2 (30% of roof area) Intensive green roof substrate depth 250mm - 1100m^2 (40% of roof area). White EPDM 825m^2 (30% of roof area) with 413m^2 mono-crystalline PV (50% by area).
Multi-8	Extensive Sedum with Mono-crystalline PV High Albedo Roof with Solar Thermal Panels	Extensive sedum for 1375m^2 (50% of area) with 688m^2 of PV (50%). High albedo white PVC 1375m^2 (50% of area) with 688m^2 of Solar Thermal Panels at 30% efficiency.
Mono-9	Black Bitumen with 25% PV	Black bitumen roofing felt with 688m^2 polycrystalline PV (25% of roof area)
Multi-10	Intensive Green Roof White EPDM with Rain Water Harvesting and PV	Intensive green roof substrate depth 250mm – 1925m^2 (70%) White EPDM – 825m^2 (30%) with 50% PV and RWH.
Multi-11	Gravel with PV and Solar Thermal	Gravel (50mm depth) - 2750m^2 (100% area) with 1238m^2 PV (45% of roof area) and 138m^2 solar thermal panels (5% of roof area)

14.3.4 Assign value

Utilising the results from the nearest modelling run to the location, the roof selection tool draws upon the most appropriate climate specific data for the different roof options from previous modelling. Additionally, with respect to rule of thumb calculations, the most relevant values are also looked up for other aspects. This is done rapidly utilising the DST. The results are presented in the values for the total roof where appropriate.

The values for multi-roofs are summed up based upon their respective areas for the total scores. These are shown in Figure 14—22. An area weighted average is taken to be a representative value when showing per m^2 values of performance as shown in Figure 14—23.

	Capital Costs (£)	Energy Consumption (kWh)	Energy Production		Ecology and Biodviersity (Species Index x Area)	Water Runoff (litres)	Rain water harvesting (litres)	Urban Heat Island (degree hours above 20°c x Area)	Materials		and Publicity (Direct rating x Area)	Amenity Space (m^2)	Aesthetics (Direct rating x Area)
			Electricity Production (kWh)	Hot Water Producion (kWh)					Embodied Carbon (kg)	Durability (Area x Years)			
Mono-1	302500	148957	0	0	30250	772750	0	51034500	508750	192500	22000	0	22000
Mono-2	137500	174378	0	0	0	1251250	0	34949750	412500	96250	5500	0	11000
Mono-3	275000	165358	0	0	0	1251250	0	63112500	412500	96250	0	0	0
Mono-4	385000	145695	0	0	66000	445500	0	48507250	577500	192500	27500	2750	27500
Mono-5	247500	174378	200420	0	0	1251250	0	55074250	412500	96250	16500	0	20900
Mono-6	302500	160023	0	0	0	1188000	0	50250750	495000	96250	8250	0	13750
Multi-7	339625	159270	65505	0	26400	928950	0	50946775	528000	134750	19663	1925	19663
Multi-8	371250	161667	109175	238631	15125	1012000	0	68513500	460625	144375	24750	0	26125
Multi-9	350625	165358	107663	0	0	1251250	0	76542813	412500	96250	5500	0	5500
Multi-10	446875	153475	65505	0	0	311850	375375	54309475	528000	163625	30388	1925	24613
Multi-11	756250	160023	196515	47726	0	0	1188000	73295475	495000	96250	39600	0	13750
Max	**756250**	**174378**	**200420**	**238631**	**66000**	**1251250**	**1188000**	**76542813**	**577500**	**192500**	**39600**	**2750**	**27500**
Range	**618750**	**28683**	**200420**	**238631**	**66000**	**1251250**	**1188000**	**41593063**	**165000**	**96250**	**39600**	**2750**	**27500**
Min	**137500**	**145695**	**0**	**0**	**0**	**0**	**0**	**34949750**	**412500**	**96250**	**0**	**0**	**0**

Figure 14—22 Excerpt from DST comparing the performance of different option across the entire roof

For each attribute for each option in Figure 14—22, Figure 14—23 and Figure 14—24 is also coloured in terms of its relative performance (red signifies poor relative performance, green signifies good relative performance. Additionally, the ranges are also shown at the bottom of Figure 14—22 and Figure 14—23, to give the decision maker a good understanding of the difference between the best and worst performing option. This also makes it clear which way is considered the best end of the spectrum, which may provide clarity to a client who is not as aware with respect to the performance of different roof attributes.

	Capital Costs (£/m^2)	Energy Consumption (kWh/m^2)	Energy Production		Ecology and Biodviersity (Species Index)	Water Runoff (litres/m^2)	Rain water harvesting (litres/m^2)	Urban Heat Island (area weighted average degree hours above 20°c)	Materials		Innovation and Publicity (direct rating)	Amenity Space (m^2)	Aesthetics (direct rating)
			Electricity Production ((kWh/m2)	Hot Water Producion (kWh/m2)					Embodied Carbon (kg/m^2)	Durability (years)			
Mono-1	110	54	0	0	11	281	0	18558	185	70	8.0	0	8.0
Mono-2	50	63	0	0	0	455	0	12709	150	35	2.0	0	4.0
Mono-3	100	60	0	0	0	455	0	22950	150	35	0.0	0	0.0
Mono-4	140	53	0	0	24	162	0	17639	210	70	10.0	1	10.0
Mono-5	90	63	73	0	0	455	0	20027	150	35	4.3	0	5.4
Mono-6	110	58	0	0	0	432	0	18273	180	35	3.0	0	5.0
Multi-7	123.5	58	24	0	9.6	337.8	0	18526	192	49	6.2	0.7	6.2
Multi-8	135	59	40	87	5.5	368	0	24914	167.5	52.5	6.0	0	6.3
Multi-9	127.5	60	39	0	0	455	0	27834	150	35	1.6	0	1.6
Multi-10	162.5	56	24	0	0	113.4	136.5	19749	192	59.5	7.6	0.7	6.2
Multi-11	275	58	71	17	0	0	432	26653	180	35	5.8	0	2.0
Max	**275**	**63**	**73**	**87**	**24**	**455**	**432**	**27834**	**210**	**70**	**10**	**1**	**10**
Range	**225**	**10**	**73**	**87**	**24**	**455**	**432**	**15125**	**60**	**35**	**10**	**1**	**10**
Min	**50**	**53**	**0**	**0**	**0**	**0**	**0**	**12709**	**150**	**35**	**0**	**0**	**0**

Figure 14—23 Per m^2 area weighted average performance of the different roof options

The final aspect of assigning values, would be to make the relevant values, dimensionless. This allows the values to be weighted and summed into a final score if required by the decision maker. It should be noted that as outlined in Goodwin and Wright (2009) decision makers often have difficulties weighting ‘costs’ and therefore there is an option to not convert this attribute into a dimensionless value. Attributes representing social and environmental value will only be converted in such a case.

Whilst the scores are converted using a value function, it should be noted that this is done automatically using linear interpolation between the best scoring and worst scoring option on each attribute. This is a simplification of the process and removes the effort required to do this by the decision maker. The reason why an automatic linear interpolation is performed is that setting up manual value functions will take additional time and a trained user. In many project situations this may not be ideal so a simplistic automatic function is therefore applied. Additionally, this is considered appropriate by Edwards and Barron (1994) if the improvement at either end of the scale are not considered more than twice as important as at the other end of the scale. Through the linear interpolation process the values are all converted to a score between 0 and 100% during this process. The outcome of this for this particular decision is shown in Figure 14—24. This also shows normalised values for costs, however the original values are also kept and the user of the tool can switch between normalised and original values at any point. It should be noted now that all scores are normalised so the highest number for each attribute represents the best roof option for that particular attribute.

	Capital Costs	Energy Saving	Energy Production		Ecology and Biodviersity	Water Runoff	Rain water harvesting	Urban Heat Island	Materials		Innovation and Publicity	Amenity Space	Aesthetics
			Electricity Production	Hot Water Producion					Embodied Carbon	Durability			
Mono-1	73%	89%	0%	0%	46%	38%	0%	61%	42%	100%	80%	0%	80%
Mono-2	100%	0%	0%	0%	0%	0%	0%	100%	100%	0%	20%	0%	40%
Mono-3	78%	31%	0%	0%	0%	0%	0%	32%	100%	0%	0%	0%	0%
Mono-4	60%	100%	0%	0%	100%	64%	0%	67%	0%	100%	100%	100%	100%
Mono-5	82%	0%	100%	0%	0%	0%	0%	52%	100%	0%	43%	0%	54%
Mono-6	73%	50%	0%	0%	0%	5%	0%	63%	50%	0%	30%	0%	50%
Multi-7	67%	53%	33%	0%	40%	26%	0%	62%	30%	40%	62%	70%	62%
Multi-8	62%	44%	54%	100%	23%	19%	0%	19%	71%	50%	60%	0%	63%
Multi-9	66%	31%	54%	0%	0%	0%	0%	0%	100%	0%	16%	0%	16%
Multi-10	50%	73%	33%	0%	0%	75%	32%	53%	30%	70%	76%	70%	62%
Multi-11	0%	50%	98%	20%	0%	100%	100%	8%	50%	0%	58%	0%	20%

Figure 14—24 Normalised scores to 100%

The normalised scores are now ready for weighting which is described in Section 14.3.5. The next two sections consider ways of modelling performance and also categorising existing peer review research for use in the DST.

14.3.5 Weightings

This process is a relatively simple and easily applied through the “swing weighting” method (Edwards and Barron, 1994, Goodwin and Wright, 2009). This asks the user of the tool to consider a hypothetical roof which performs at the least preferred levels in all attributes. Then the person is asked, if they change one attribute from the worst level of performance to the best level of performance, which would this be? After this, they are asked to pick the next attribute which they would like based on its swing from the worst performance to the best performance. The process continues for all the lowest level attributes in the decision tree. This ranks the attributes in order of preference. To make it easier for the user of the tool to see which are the best and worst, these are highlighted as shown in Figure 14—22 and Figure 14—23.

The top attribute is then automatically scored an arbitrary number. For simplicity this is chosen to be 100. The user of the tool then has to input, relatively speaking how important the swing in the next performance characteristic is in relation to the first. For example if the swing in performance from the worst to the best was considered 70% as important as the attribute score 100, then the second attribute would get a weighting of 70%. This process continues for all the variables.

This is demonstrated for the attributes selected as important for this decision. Capital costs are excluded in this case. Ideally this process itself would be done in collaboration with the stakeholders of the project, but is shown for illustrative purposes in Figure 14—25.

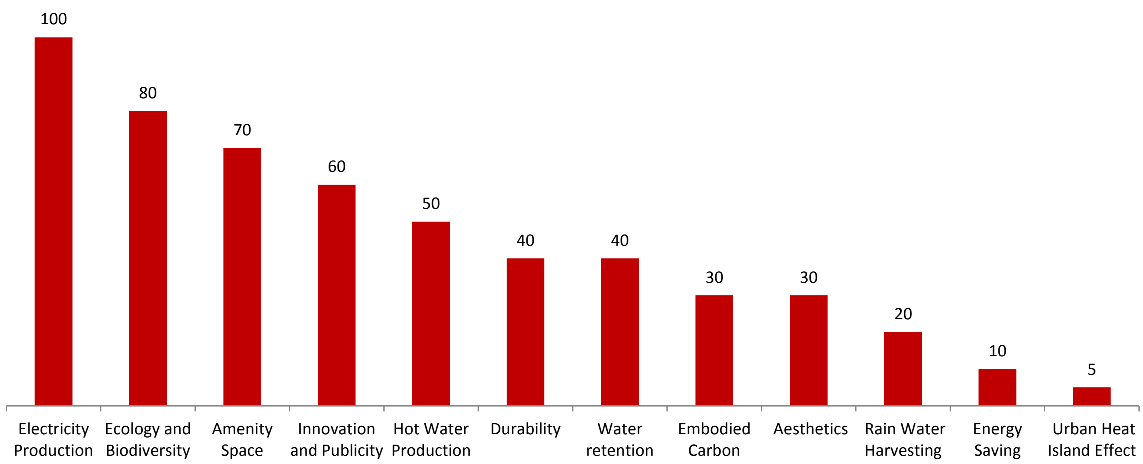


Figure 14—25 Swing weights as applied to the attributes

These are input into the tool, which automatically normalises the weights to add up to 100. At this stage you can see the relative weights of the higher level attributes, such as ‘environmental and social’. This is an important sense check as to whether the weights on the sub attributes are reflective of the overall decision. For example, if the approximate split of Environmental aspects was not 70 vs. 30, then this should be reviewed and changed by the decision makers.

	Environmental									Social			
	70.1									29.9			
		Energy Production						Materials					
Normalised	Energy Saving	28.0		Ecology and Biodviersity	Water Runoff	Rain water harvesting	Urban Heat Island	13.1		Innovation and Publicity	Amenity Space	Aesthetics	
		Electricity Production	Hot Water Producion					Embodied Carbon	Durability				
	1.9	18.7	9.3	15.0	7.5	3.7	0.9	5.6	7.5	11.2	13.1	5.6	100
Swing Weighting Input By User	10	100	50	80	40	20	5	30	40	60	70	30	

Figure 14—26 Swing weights and normalised weights at various levels of the decision tree

Further potential areas of overlap between Parts 1 and 2 include part of the weightings process, which could potentially be informed by some of the outputs of techniques developed in Part 1. This is in relation to informing the weightings for the different roof attributes.

Part 2 includes a stage in the Roof DST based for providing a weighting for each attribute. The approach taken is based on the widely recognised Swing Weighting method. This considers the swing in the performance between the best and worst performing roof option for each attribute and considers this in the weighting process. This robust approach means that if all the options on a particular attribute perform relatively similarly, then the attribute may be weighted of relatively low importance. This reduces the chance of small differences in the performance across roof options majorly influencing the decision scores by providing a large weighting for that particular attribute. Therefore, whilst it is accepted that asking people to weight an attribute without knowing the range or the swing in the performance between the best and worst performing option can have serious limitations, preliminary weightings could be based on the number of times that a particular theme occurs in the coding process of analysing “a sustainable building is…” exercise outlined in Case Study 1B. This could be used to help inform the weightings for the different roof attributes if it is not possible to engage stakeholders in the swing weighting process.

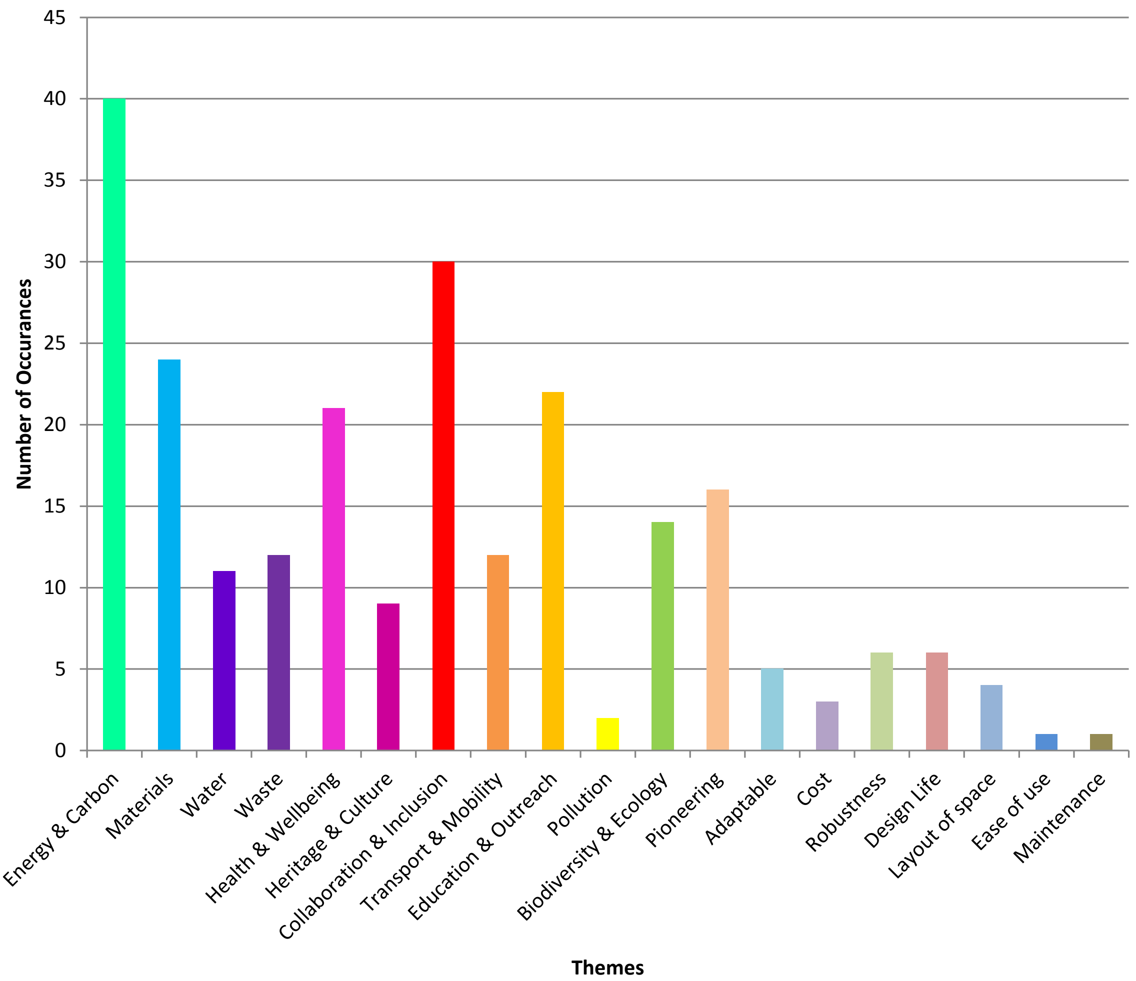


Figure 14—27 Repetition of themes by workshop participants in Case Study 1B from Part 1 to inform weightings

For example, Figure 14—27 shows the number of times post-it note comments were mentioned by the participants of the workshop outlined in relation to the themes. Based upon the assumption that the themes that were repeated the most represent the most important considerations, such numbers could inform the weighting for the attributes in the roof decision support tool. In a similar manner, the output of the values questionnaires could also be used to inform the weightings on the different roof attributes. Other engagement techniques such as the importance vs. influence work could also be used to inform the weightings of different attributes in the roof decision support tool.

However, if such an approaches are adopted, then a check should be made to consider the ratings against how the roof options are performing on any attribute. This is to ensure that the swings in performance between the best and worst option are not having a substantial impact on the overall ratings for the various roof options if they are not of significance. This could potentially be done utilising sensitivity analysis which is also incorporated into the Roof DST.

14.3.6 Results (make a decision)

The aggregated scores for the different roof options set out for the case study project are shown in Figure 14—28. This then shows the ranking of the different options excluding the impact of costs. A rank of 1 is considered the best option.

	Energy Saving	Energy Production		Ecology and Biodiversity	Water Runoff	Rain water harvesting	Urban Heat Island	Materials		Innovation and Publicity	Amenity Space	Aesthetics	Overall	*Rank*
		Electricity Production	Hot Water Producion					Embodied Carbon	Durability					
Mono-1	1.7	0.0	0.0	6.9	2.9	0.0	0.6	2.3	7.5	9.0	0.0	4.5	**35.2**	*6*
Mono-2	0.0	0.0	0.0	0.0	0.0	0.0	0.9	5.6	0.0	2.2	0.0	2.2	**11.0**	*9*
Mono-3	0.6	0.0	0.0	0.0	0.0	0.0	0.3	5.6	0.0	0.0	0.0	0.0	**6.5**	*11*
Mono-4	1.9	0.0	0.0	15.0	4.8	0.0	0.6	0.0	7.5	11.2	13.1	5.6	**59.7**	*1*
Mono-5	0.0	18.7	0.0	0.0	0.0	0.0	0.5	5.6	0.0	4.8	0.0	3.0	**32.6**	*7*
Mono-6	0.9	0.0	0.0	0.0	0.4	0.0	0.6	2.8	0.0	3.4	0.0	2.8	**10.9**	*10*
Multi-7	1.0	6.1	0.0	6.0	1.9	0.0	0.6	1.7	3.0	7.0	9.2	3.5	**39.9**	*5*
Multi-8	0.8	10.2	9.3	3.4	1.4	0.0	0.2	4.0	3.7	6.7	0.0	3.6	**43.4**	*2*
Multi-9	0.6	10.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	1.8	0.0	0.9	**18.9**	*8*
Multi-10	1.4	6.1	0.0	0.0	5.6	1.2	0.5	1.7	5.2	8.5	9.2	3.5	**42.8**	*3*
Multi-11	0.9	18.3	1.9	0.0	7.5	3.7	0.1	2.8	0.0	6.5	0.0	1.1	**42.8**	*4*

Figure 14—28: Aggregated benefits and ranking according to sub attributes

The scores for each option can also be presented at a higher level of the hierarchy, for example the environmental and social value level as shown in Figure 14—29.

	Environmental	Social	Total
Mono-1	21.8	13.5	35.2
Mono-2	6.5	4.5	11.0
Mono-3	6.5	0.0	6.5
Mono-4	29.7	29.9	59.7
Mono-5	24.8	7.9	32.6
Mono-6	4.7	6.2	10.9
Multi-7	20.2	19.6	39.9
Multi-8	33.1	10.3	43.4
Multi-9	16.2	2.7	18.9
Multi-10	21.7	21.2	42.8
Multi-11	35.2	7.6	42.8

Figure 14—29: Scores for each roof option at an environmental and social level

All the results presented thus far exclude costs as this was not given a weighting earlier in the approach. To consider costs, the costs are plotted vs. the overall total for environmental and social benefits as shown in Figure 14—30 (note the reversal of the horizontal axis). This then allows the decision maker understand the trade-off between costs and the environmental and social benefits of each option. This aligns with the approach taken to increase value in Section 7.1, which can either be to increase benefits or reduce costs.

The benefits are classed as the sum of the environmental and social considerations for each roof option, which are then plotted against the costs as shown below. This gives a front of options that perform the best. Anything that is not on this front should be considered non-optimal or 'dominated' by other options. This is a particularly useful way to assess the performance of options, as it allows informed dialogue with the client / project stakeholders when considering how much extra they are willing to pay for each incremental improvement in the social and environmental benefit of the roof option. The highest value option in the eyes of the client can then be made.

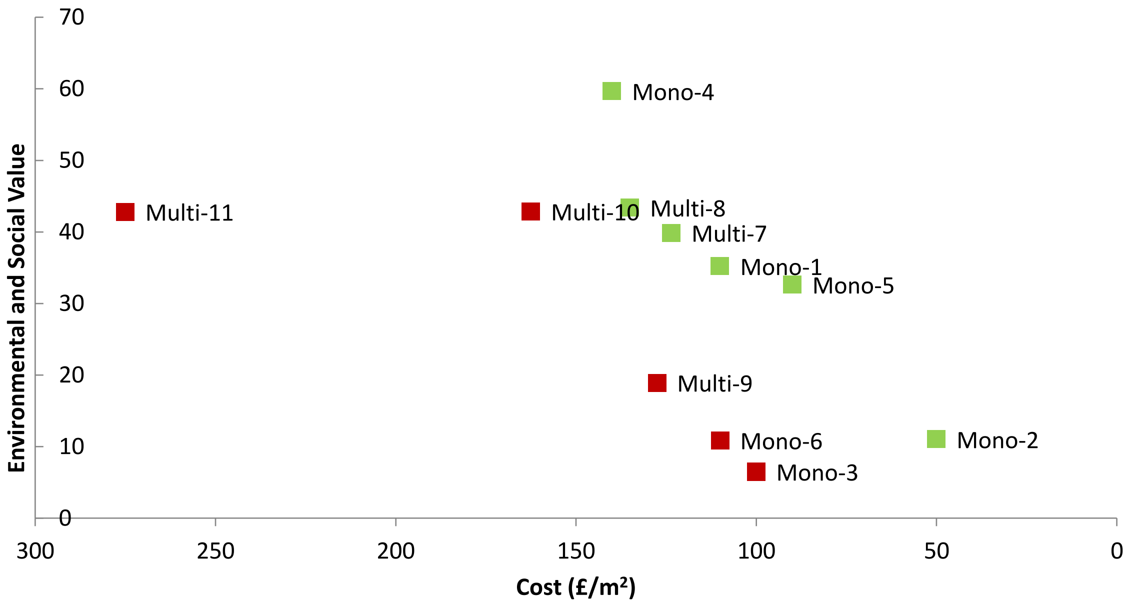


Figure 14—30: The cost vs. environmental and social value

The green markers in Figure 14—30 show the roof options on the ‘efficient frontier’. This demonstrates the best options from a cost / environmental and social value perspective. For example, option “Mono-2” represents a cheapest roof but it is also relatively low value from an environmental and social perspective. Red markers show options which are classed as ‘dominated’ by options on the efficient frontier. For example “Mono-2” dominates “Mono-3” and “Mono-6”, as it offers higher environmental and social benefits and it also costs less money. Therefore, this offers a higher value option. Mono-5 also dominates options Mono-3, Mono-6 and Multi-9, as it outperforms these options from an environmental perspective but also costs less money. The best performing option from an environmental and social perspective is “Mono-4”, however this is also the third most expensive. The decision maker, if operating in a totally rational way would pick one of the options on the efficient frontier, trading the benefit of the increase in environmental and social benefit for each option on the efficient frontier with the increase in costs when considering which option to pick.

The roof selection tool has the purpose of informing the decision, but not actually making the decision. For example, the decision maker may wish to not go with an option on the efficient frontier for reasons not considered in the decision tool. This may be because of considerations such as the particular option is difficult to source and construct in a particular location. This is understandable and thus should not be ignored. However, the tool should provide clear guidance in relation to the different options for the attributes considered.

It should be noted that the tool can also be used to inform the development of new options. For example the user may see trends from the insight derived through the process and decide to develop a new option utilising a different combination of roof types. This will be automatically updated through the tool and the user can check that the weightings applied to the swing between the best and worst options are still appropriate. New rankings will then be applied.

The final thing that remains is to make a provisional decision, after having analysed the output of the decision tool. This rests with the decision makers. The tool merely provides a robust structure and set of information, whereby it is argued that a perfectly rational person would follow. However, it is understood for many reasons, which may include something not being considered in the decision support tool, the decision maker may go against the recommended option.

The decision is simply made by selecting the preferred option from a drop down list of the options. This is then recorded by the DST for future reference, along with the performance of all the other options under that particular weighting regime, thus providing an audit trail. Upon making a decision on which roof option to progress, the user of the decision tool is asked to provide a comment on the reason for the choice. This will also be recorded in a database to understand how users make decisions with respect to roofs and also understand how often the options shown to be the best by the decision support tool is selected. It is hoped that this can provide valuable learning to inform the future development of the tool.

14.3.7 Consider risk

When the provisional decision has been made, the decision should then be checked for its robustness, which can be done in the decision tool. An example is shown below, demonstrating the impact of changing *'Electrical Energy Production'* from having a weight of 100 to having a weight of 0. This demonstrates the sensitivity of changes to this attribute. This shows that for the roof option with the highest environmental and social benefits (Mono-4), the swing in weight between 0 and 100 for Electricity Production does not influence its rank. However, options such as “Multi-11” are significantly influenced by the swing in weighting, dropping down two places with respect to their rank.

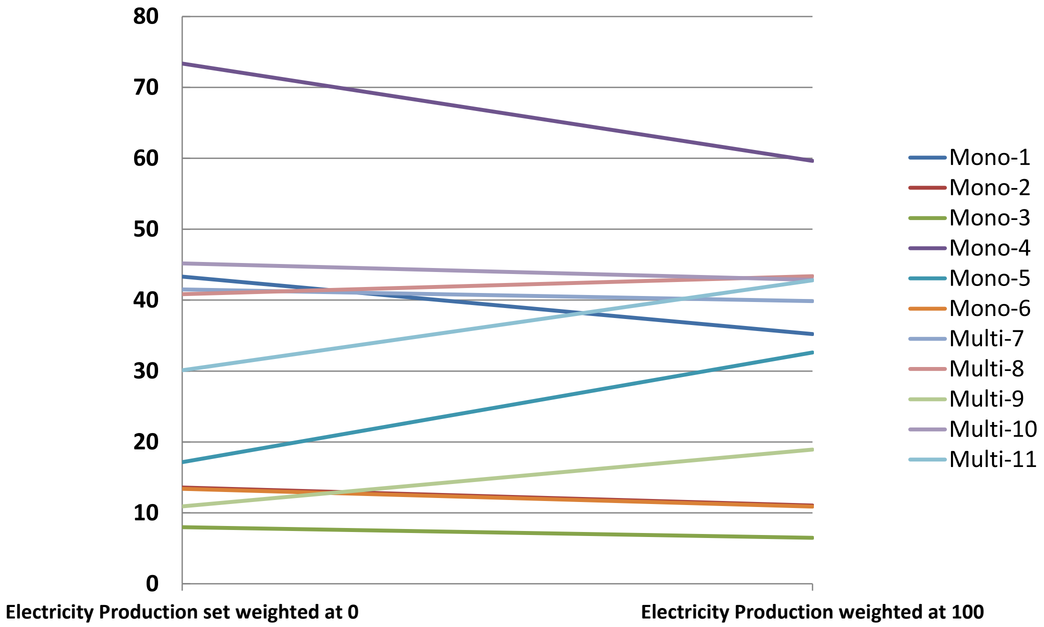


Figure 14—31 Sensitivity analysis for changes in weight on electricity production

This also influences the efficient frontier and the changes with respect to this can also be seen in Figure 14—32. This shows that options Multi-7 and Multi-8 are now dominated. Additionally it shows that to achieve increasing levels of value with respect to the efficient frontier will require increasing costs. However, large increases in value can be achieved for progressively smaller increases in cost in this situation.

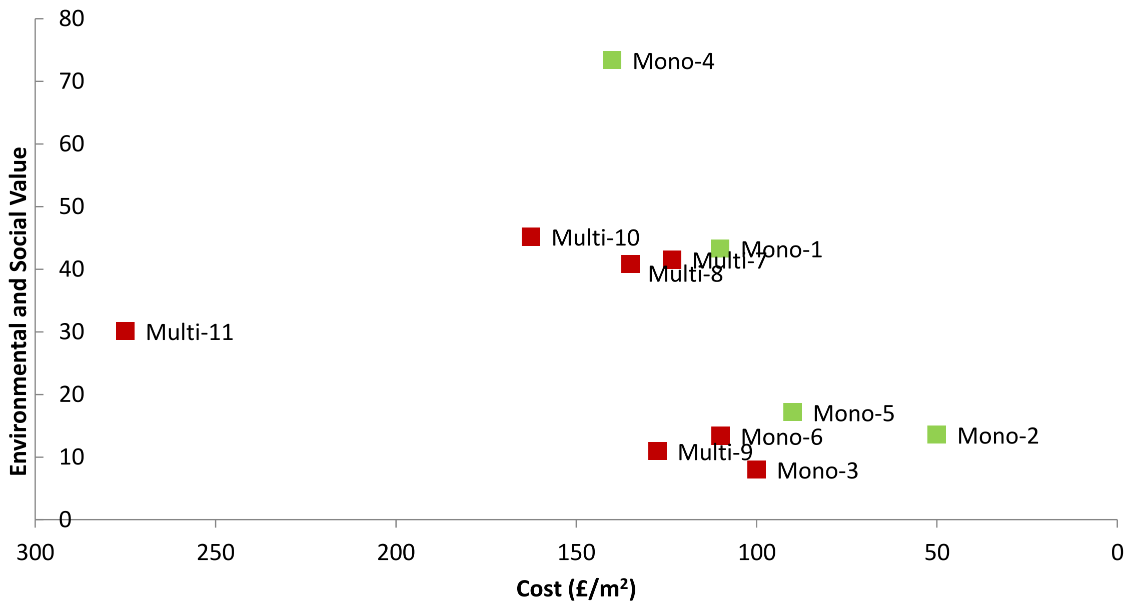


Figure 14—32: New efficient frontier for changes in weight on electricity production

The decision maker is encouraged to consider the sensitivity of the decision to changes and also consider how new options could impact on this.

With respect to the risk of implementing green roof systems in the location of the project (East Anglia, in the UK), the closest weather file to the site was looked up, using the approach defined in Section 14.2.7 and defined to be Cfb. This was the third most common type of climate type with 216 green roofs contained within the database installed on buildings within this climate type. Additionally, there was a good range of green roof types, with a spread of extensive to intensive installed in the climate type as shown in Figure 14—33. The figure shows less sub categorisations such as semi-extensive and semi-intensive, however, these lie between the extremes of extensive and intensive roofs.

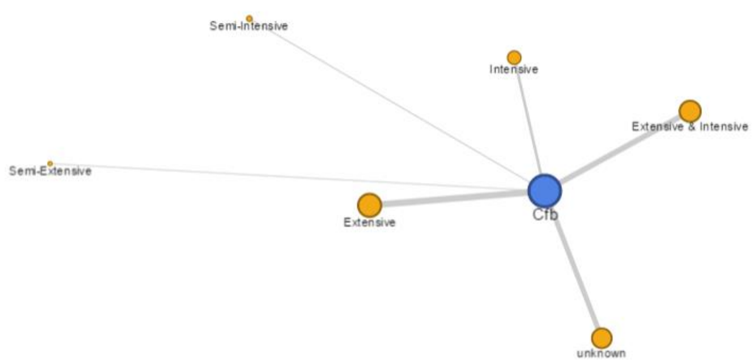


Figure 14—33: Showing the climate type of the project in question (blue node) and the types of green roofs (yellow node). The weight of the lines represents the number of m2 of each type of roof

In relation to cooling and heating degree days of the location of other green roofs, it is in a well-populated area of the chart, suggesting that the risk of installing green roofs in this location is reduced, see Figure 14—34.

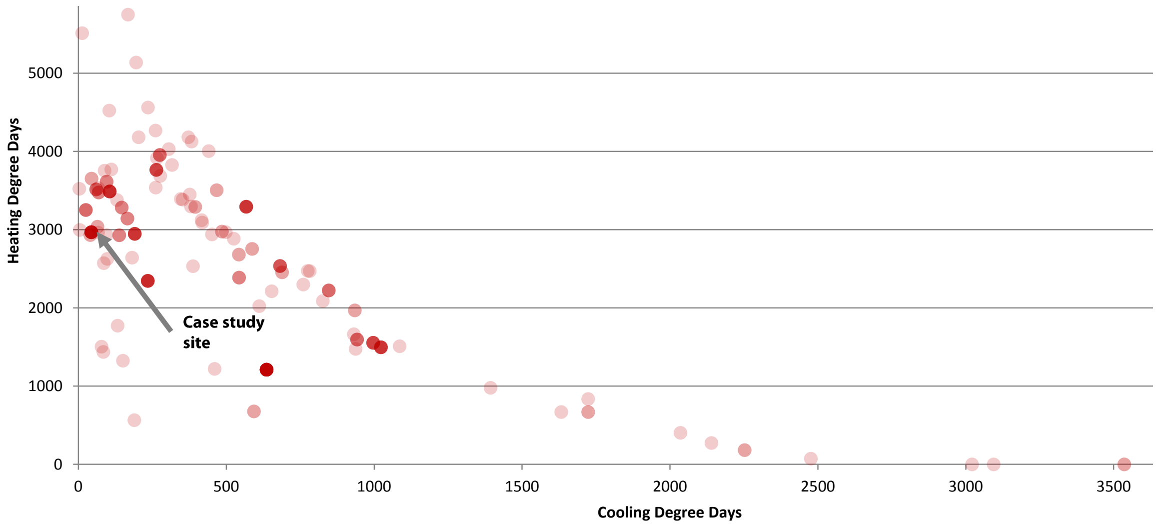


Figure 14—34 Case study site in relation to cooling and heating degree days

14.4 Discussion

The approach to sustainable roof selection and prototype DST presented in this section provide a rapid way of bringing together a significant amount of information quickly and providing values to inform decision making. It also provides a way of merging several different roof types for use over an entire roof area to quickly assess the combination of options. It significantly adds to knowledge in these areas drawing on leading academic research to inform the information that is input into the decision support tool. A roof decision support tool that combines roof options in such a rapid way has not previously been developed and this represents a contribution to knowledge.

The tool is designed to be used at the start of the design process when the ability to influence sustainability is the greatest and where information is typically lacking and uncertainty subsequently high. However, the information could also be used to inform the further development of design of options and also inform the generation of further alternatives.

It builds upon earlier work by authors such as McCourt (2007) and Grant (2007), by providing a way of rapidly acquiring relevant context specific roof performance data. It takes elements of computer programming, decision analysis, leading roof performance evaluation techniques, building simulation modelling and combines them to provide guidance on the sustainability and value of various roof options. It also considers how different elements of problem structuring can potentially be brought together to decide on the decision objectives. The example provides an overview of how the output of a stakeholder engagement workshop, which is shown as research in Part 1, could be useful in informing the choice of attributes for decision making. This is further discussed in the following section, regarding how Part 1 and Part 2 of this thesis can be synthesised to inform sustainable roof selection.

The tool provides an auditable and logical approach utilising the widely used and accepted Simple Multi-Attribute Rating Technique (SMART). General benefits of this approach are as follows (Goodwin and Wright, 2009):

- An auditable approach based upon a set of axioms.
- A way of structuring decision problems that involve multiple objectives. Research has shown that unaided decision makers tend to avoid making trade-offs meaning that the good performance by options on one objective is not allowed to compensate for their weaker performance on other objectives.
- Allows the decision maker to be able to better explain and justify why a particular option is favoured through the structure provided.

General benefits of the approach to sustainable roof selection and accompanying decision support tool (DST) include:

- The structure to the decision support tool developed also includes methods of gaining the most reliable information regarding the performance of roofs in different climates and contexts. This has been difficult to do prior to this work
- It does not enforce a set of decision objectives; these can be selected from a list of options or defined by the user for a particular context. Therefore the decision attributes can be defined to be representative of the decision context.
- The structure of the tool allows information to be collected rapidly on many attributes, meaning this can be done quickly at the start of projects, thus the DST has the ability to influence decisions when the opportunity to integrate sustainability is at the highest in the design process.

With respect to the work conducted here the various stages of the decision support tool (see Figure 14—35) are briefly discussed over the next sections.

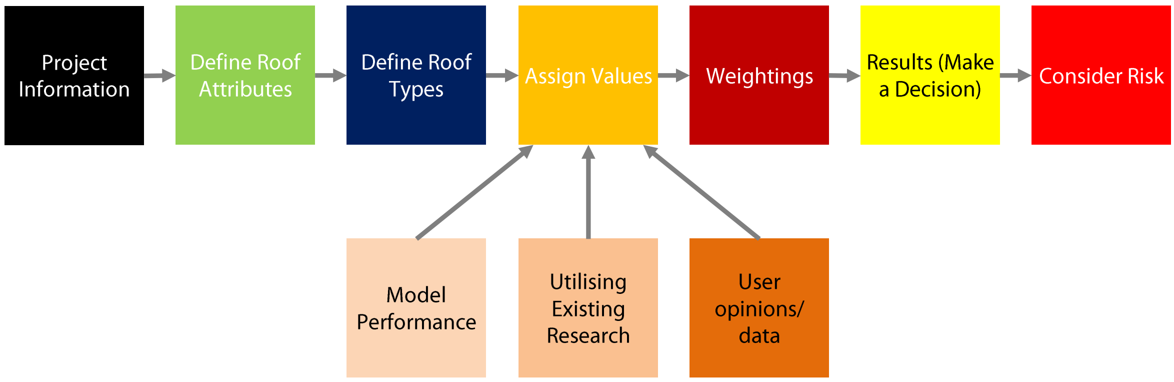


Figure 14—35 Stages of the approach to sustainable roof selection

14.4.1 Project information

This provides a way of inputting key project information, which can then be used to look up the most appropriate whether file which will be used to identify the performance of the various roof options with respect to various decision making characteristics. Additionally, a way of assessing the likely importance of the roof in relation to the project as a whole is incorporated in this stage. This should be utilised as an indicator to assessing whether it is worthwhile spending time (and money, in the industrial context) assessing the performance of various roof options.

Additionally, the project information asked for is important in considering the implications of the roof on BREEAM (BRE, 2011) , LEED (US Green Building Council, 2009) and Estidama (Abu Dhabi Urban Planning Council, 2010) criteria. It was also demonstrated as an important factor in Nelms et al. (2007) who showed for different building types (high-rise vs low-rise) that there could be significant differences on the performance of roofs on the project as a whole. Such information will also be stored in a database, which for audit purposes will be important and will allow traceability of the decision making process that has been undertaken. This is not considered in Grant (2007) or McCourt (2007) other than mentioned as a limitation by McCourt.

14.4.2 Define roof attributes

Through the research a set of roof attributes, typically considered with respect to sustainable roof selection, has been defined and a set of criteria has also been defined, through a review of the literature on green roofs, cool roofs, solar technologies and rain water harvesting, to create a checklist for consideration as part of the approach. This is also included within the approach to sustainable roof selection and accompanying decision support tool. This provides the largest known set of roof attributes identified with respect to sustainability from a comprehensive review of the literature. This also included attributes related to environmental assessment methods that are commonly used, such as BREEAM, LEED and Estidama. It is intended that not all the roof attributes would be selected for any given project, but the user of the Roof DST should choose those that are most applicable to the project. This could be informed by the output of stakeholder engagement techniques developed in Part 1 of the research.

It is accepted by the researcher that design decisions are highly context dependent and it is therefore difficult to plan for every alternative in advance, as many variables will change on a project by project basis (de Blois and De Coninck, 2008). However, the list of roof attributes also provides a way of translating requirements into meaningful indicators, which is considered a problem that many stakeholders struggle with (Alwaer and Clements-Croome, 2010). Additionally, the indicators provide a useful checklist of considerations. As detailed in Section 14.2.2 a study by Bond et al. (2008) showed that participants consistently emitted nearly half the objectives that they considered important. In a follow up study Bond et al. (2010) looked into reasons for this and ways in which more comprehensive lists of objectives could be developed. A variety of interventions were tested, which included the provision of sample objectives, organisation of objectives by category, and direct challenges to do better. Organisation of objectives by category and direct challenges to do better both improved the elicitation of objectives. Providing a sample set of objectives did not improve the generation process. Therefore, it is proposed that stakeholder considerations for sustainability are elicited unprompted, but the list then acts as a final checklist of considerations, also highlighting roof related criteria from the environmental systems of BREEAM, LEED and Estidama.

Additionally, it is considered that the approach developed here sits between two ideological paradigms of “expert-led and top down” and “community-based and bottom-up” (Reed et al., 2006).

The relationships between the techniques used in Part 1 of the thesis are considered in the selection of roof criteria in Section 14.3.2. Additionally, included in this section is a diagram representing the inter-relationships of the roof attributes, to help inform the decision maker of areas where double counting may be problematic if those attributes are included together in the DST.

Additionally, whilst there is a list of roof decisions, defined through the literature review, included as a checklist in the approach to support sustainable roof selection, the user can also enter further decision attributes if these are considered important and relevant to the roof selection. This allows the expansion of the list to potentially address wider issues or issues specific to a given context. It is intended that this list will grow over time. It should be noted that with respect to the performance of various roof options for user defined attributes, they will have to be scored based on user input.

It is considered that the approach to defining roof attributes is much more comprehensive compared to the work of Grant (2007), McCourt (2007) and Nelms et al (2007). For example, the approach considers how the output of problem structuring methods, to gain an insight into what stakeholders think is important for a problem, can be used to structure decision objectives around a value focused thinking approach. This has the advantages of being able to incorporate the values of stakeholders of the project into the roof decisions. Additionally, linking the roof criteria as defined through a comprehensive review of the literature to project level objectives, provides a more tangible link of how the roof performance potentially links to what stakeholders consider of value.

After constructing the value tree showing the decision attributes, Keeney and Raiffa (1976) suggested that the tree should be reviewed under the five following criteria. These are outlined below with the assessment for this large decision tree. The prototype DST prompts the decision maker to review their selected criteria under these headings. This ideally should be assessed on a case by case basis depending on the project context; it is not anticipated that the full list of decision criteria would be considered for each decision. Additionally, the list of attributes is only included as a common list of considerations and the DST also allows for additional attributes to be considered.

14.4.2.1 Completeness

This refers to whether or not the tree is complete from the perspective of the decision maker. If so, all decision attributes that are of concern to the decision maker will be included in the value tree. In an attempt to ensure an adequate level of completeness the decision attributes were defined through a thorough review of the roof literature and factors that typically are used to assess roofs through environmental assessment methods. This therefore includes 47 value attributes at the lowest level of the value tree. These are broken down as follows:

- 14 Environmental value attributes
- 4 Social value attributes
- 2 Economic value attributes
- 10 BREEAM value attributes
- 7 LEED value attributes
- 10 Estidama value attributes

This is a comprehensive set of attributes for roof systems and covers Environmental, Social and Economic Considerations. However, the completeness (or not) of the tree will be dependent on the context of the project and the importance of the decision. Therefore, the approach and prototype roof DST is able to accept further attributes if required for the project.

14.4.2.2 Operationality

Operationality considers whether the lowest-level attributes in the tree are specific enough for the decision-maker to evaluate and compare them for the different options. In order to achieve this, the decision tool includes calculation procedures and data, which can evaluate the different options at this level reasonably quickly. Therefore, this criterion is considered satisfactory. This is not to say that they are simplistic to calculate, in fact for example, many studies have just focused on looking at the variables to understand the whole life cost implications of green roofs. The number of variables in such a study can be large. However, with reference to the literature review in this thesis, information included in Appendix O to Appendix S regarding performance of various types or roof and the data included in the tool, each value attribute should be able to be scored by the user, provided they are trained built environment professional.

14.4.2.3 Decomposability

This criterion requires that the attractiveness of a roof system on one attribute can be assessed independently of its attractiveness on other attributes. Decomposability allows the decision-maker to focus on how well each option performs on each attribute separately, without the need to think at the same time about their performance on other attributes (Goodwin and Wright, 2009).

The value tree as it currently stands is not considered decomposable by the author as some criteria are related such as energy use and operational costs. This will require consideration from the decision maker. Whilst, many of the environmental value criteria overlap with those of BREEAM, LEED and Estidama, it should be noted that the method of assessing performance for each system, relies on a different process and is typically unique to each criteria. Additionally, it would be one EAM that would be used, i.e. either BREEAM, LEED or Estidama, and rarely would two or more be considered for the same project. The three assessment systems are included in the decision tree at present for completeness.

14.4.2.4 Absence of redundancy

This is to check that two or more attributes are not considering the same thing. This check is essentially to avoid double counting due to one or more attributes representing the same thing. Double counting has the consequence of possibly overweighting particular attributes if not done explicitly. As discussed in section 14.4.2.3 regarding decomposability, some attributes are referring to similar things in the decision tree (but measured differently). However, it is up to the decision maker to select the value attributes that they are interested in from this list. Again attributes from the LEED, BREEAM and Estidama have similar aims, if it is important that the project achieves points against each of these for the three rating systems, then they are not classed as redundant.

In order to reduce unintentional redundancy, the author has provided a summary of the relationships between all the decision attributes from the author’s perspective. This should be used by the person setting up the decision support tool to ensure that they are aware of possible areas of redundancy (see Figure 14—36). Further work would be to refine this, by asking numerous industry professionals to score how strongly related each attribute is from their perspective and utilising this to reduce bias and gain a collective view on the relationships between attributes.

With respect to redundancy, it is considered very difficult to achieve total redundancy in this particular context. For example, with respect to the energy category, this also has an in-use cost implication. For example, each area which considers energy reduction / production in each environmental assessment category has a line showing a relationship between this and in-use costs, which will be reduced through the reduction of energy use / production of energy. There is an option for this to be considered when calculating the information for the in-use costs of the roof which is approximated in the decision making tool. However, this is presented separately in the value tree as both are considered important and it is considered useful.

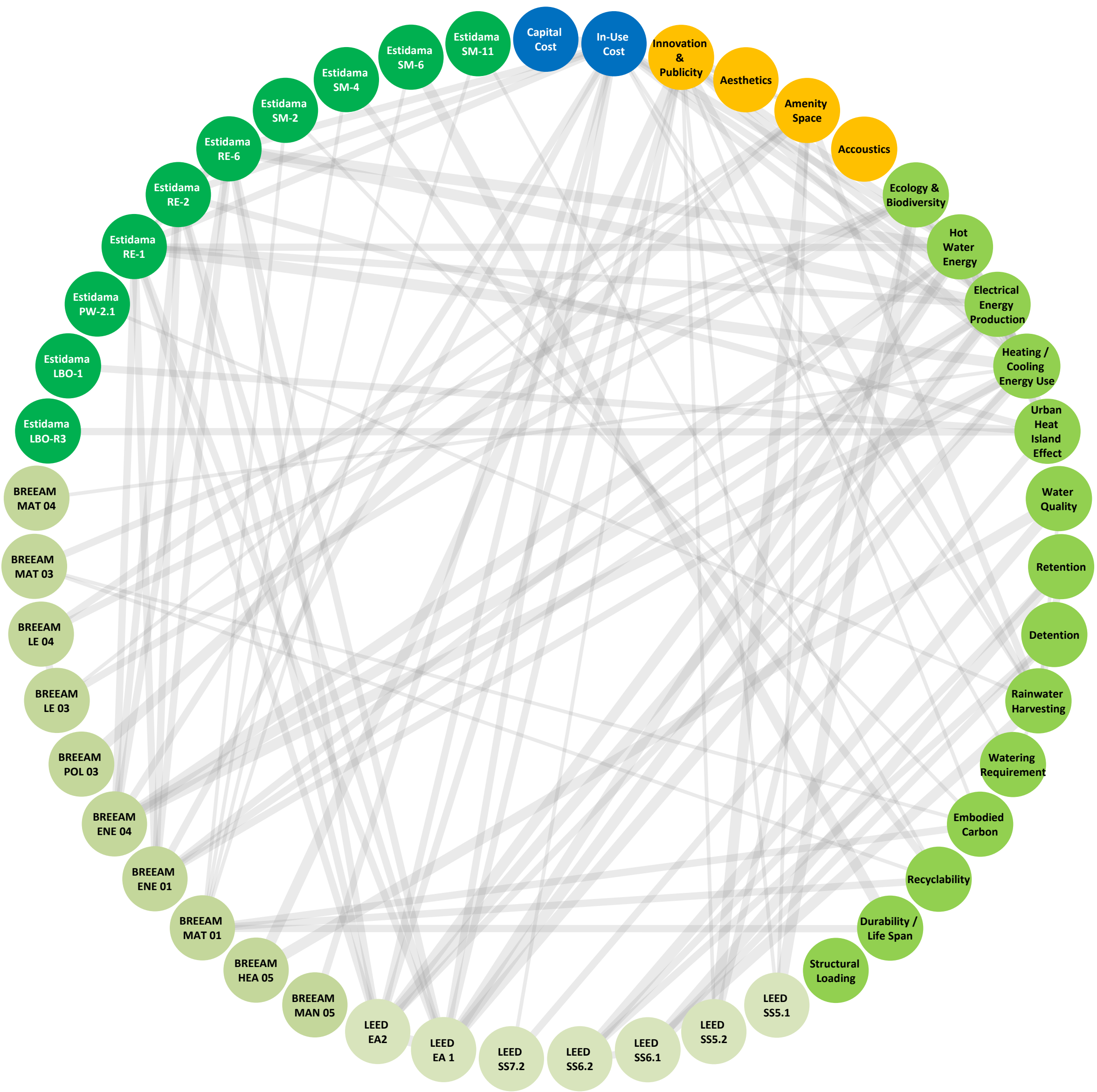


Figure 14—36 Relationships between attributes, the thicker the line the stronger the considered relationship[16]

[16] Relationships based on the thoughts of the author.

14.4.2.5 Minimum size

This is concerned with defining a decision tree of appropriate size. 47 attributes is significant, however as previously discussed it is likely that only one or perhaps even no assessment systems will be used on a project. This reduces the number of attributes to consider significantly (by around 17-20 attributes if only one assessment systems is used). Additionally, to help reduce the decision makers' mental requirements, much of the analysis and calculation is done through computational analysis of the options. Currently very few of the attributes above are considered in roof selection and thus it is likely that the decision maker will reduce the number of attributes considered further when undertaking a decision. These are included for completeness rather than to minimise size.

In some areas, for example urban heat island effect has been simplified and could have been subdivided into more value attributes to include peak effects and annual effects. However, this is considered overwhelming by the researcher and in the interest of keeping the value tree at an appropriate size is thus simplified to one attribute which will be calculated through modelling.

14.4.3 Define roof types

This part of the tool includes a set of roof options for selection by the user of the decision support tool for assessing the performance in relation to the decision attributes. Whilst the list is limited, it is more than is included in any other roof selection tool or framework, additionally the prototype Roof DST has the ability to combine roof options over different areas to build up a roofscape. This is a novel approach and means that countless number of roof scape options can be developed and assessed against the decision attributes quickly. Additionally, some roof system types can be placed on top of one another, such as solar technologies on top of all roof types. As many options as the user wishes to assess can be added to the roof types.

However, no testing of the accuracy of this approach has been done. Therefore it is identified as an area of further work. This would involve testing how close the weighted average of various roof types was to a fully modelled scenario to represent a combination of roof types. This would provide a check to how close the results were.

Additionally, with respect to putting “optional technologies” above the roof, this does not consider the implication of shading on the “water proofing and surface coverings”. The researcher tried an approach to do this as outlined in Scherba et al. (2011), however could not achieve the same results as the other authors. Thus did not proceed further with their approach. Further work in this area would be beneficial.

14.4.4 Assign values

For assigning values to represent the performance of roof options against the decision attributes, two broad techniques have been developed. Additionally, the user can input their own data on whichever attribute using a direct rating method. The tool development builds up on previous work and reviewed literature which did not consider the need for rapid data acquisition and how this could potentially be done from existing literature in a more structured way. This was highlighted as an area of further work by Nelms et al. (2007). The tool includes two approaches which have been developed through this research for assessing the performance of a variety of roof systems to provide quantifiable information on which to base roof decisions. These are then translated into a value function based on the performance of the other roof options that are assessed for a particular decision. This builds on the work of Sailor (2008) in terms of consideration of the performance of green roofs and links this into an approach to making more informed roof choices.

The two methods include the application of a leading set of building modelling techniques and also an approach for categorising and rapidly finding the most relevant piece of green roof research based upon the project’s climate type and the green roof type being assessed. This addresses gaps in the research relating to finding context specific information on the performance of some roof types and this significantly speeds up the process. Additionally, as outlined in the Case Study 2A finding context specific data can sometimes be time consuming. This lead to previous case study work just rating the performance of roof options qualitatively and with some degree of subjectivity. Therefore, these approaches integrated within the DST contribute to knowledge in these areas.

Limitations with some of the methods include some aspects of performance, which are relatively abstract at present. For example, urban heat island is covered utilising a proxy-measure of the temperature hours that the roof is above 20°C. Many engineers and decision makers may consider this to be relatively meaningless. Therefore, further work could be undertaken around these areas. Additionally, improved visualisations of how the performance of these options relate to heat transfers into the built environment and the building and impact on the overall resources flows for the building would be beneficial in making the data more meaningful. Whilst this may not necessarily influence the scores across the attributes, it may be powerful in communicating the importance of different aspects. The performance of options can now be objectively quantified across numerous attributes with a greater degree of confidence than at the start of the research. This research has drawn many of the techniques and research papers and synthesised this through the approaches developed and the prototype roof decision support tool.

For some aspects of performance it is possible to model the performance with respect to the location's climate variables utilising techniques outlined in the literature. However, not all attributes can be modelled with the same level of confidence for all roof options. For example with respect to the method used to model green roofs, whilst the method was published in a respected academic journal, further testing and validation would improve confidence in the method. Additionally, methods of considering roofs with a depth less than 100mm would also be beneficial, which is currently not possible through the modelling approach for green roofs.

14.4.5 Weightings

Weightings are then applied by the prototype DST based upon the normalised values created during the previous step. This is done utilising the swing weighting method. This therefore addresses the limitations of work undertaken by McCourt (2007) who applied weightings based upon the opinions of users on what was important, but didn't consider the performance of those options in the weighting. Therefore, if attributes are weighted important but the range of performance of different roof options on any given attribute is small, the weighting on that particular attribute could have a disproportionate effect on the overall decision. The swing weighting method militates against this.

The use of the output of stakeholder workshops could also be potentially used to inform the weighting of various roof attributes. This is further discussed in Section 14.3.5, however there is a strong limitation in the fact that stakeholders were not considering the performance of different options with respect to the weighting process which is defined as important by Keeney (1992).

14.4.6 Results

The results from the approach and accompanying DST can be presented in two ways based on the preference of the decision maker, this includes:

- Overall environmental, economic and social value score. This is considered if the decision maker / user of the decision support tool feels capable of weighting the importance of costs.
- The total environmental and social benefits of each roof option can be plotted against capital costs. This is useful if the decision maker does not feel able that they can weigh the importance of costs.

If the overall score is chosen as the method that the decision maker wishes to see the results, then the sum of the economic, social and environmental value of each option is given to represent the sustainability of each roof option. Each high level attribute is scored through the value function to ensure that the highest value is given to the best performing options. This assumes that the adopted stance on sustainability in this work is that the best balance of environmental, social and financial performance represents the highest value and most sustainable option. It therefore assumes tradability between economic, social and environmental capital.

Additionally, if the decision maker decides not to weight costs, the total environmental and social benefits of each roof option can be plotted against capital costs. This allows the decision maker to see the trade-off between cost and economic and social value and also establish an "efficient frontier," of roof options, which represent the best social and environmental value for a given cost. This is particularly useful, as the decision maker can then see which option gives them the most environmental and social benefit for a particular budget. Furthermore, it could be useful in justifying additional budget if large increases in environmental or social value could be achieved for a small increase in cost.

14.4.7 Consideration of risk

The final part of the approach to sustainable roof selection includes the ability to consider the risk through sensitivity analysis. A simple form of sensitivity analysis allows the user to change the weightings and see the influence on the ranking of the roof options with respect to their environmental and social value. The impact on the efficient frontier can then be established. The use of sensitivity analysis provides an approach for doing this, which is not sufficiently covered in Grant (2007) or Nelms et al. (2007). However, such an approach to risk was taken by McCourt (2007).

However, the second element of risk with respect to the climate and the survivability of green roofs, is not considered in any of the above pieces of work. In utilising the largest database of green roof data, and augmenting this with information on the climate, it is considered that a more comprehensive and useful dataset for assessing risk has been developed. This is done through a tool developed using a database of global green roofs. It essentially allows the user to input climate type and understand if there are other green roof projects in a particular climate type and what type of green roofs they are. This allows the user to find relevant case study information and be better able to assess the chances of survival of the green roofs.

14.5 Conclusion

This section has developed an approach to sustainable roof selection and accompanying decision support tool. It has brought together quantitative and qualitative information to be able to inform roof selection from the perspective of social, economic and environmental value. The approach builds on areas of further work, as defined in the literature review and the Action Research case study 2A. The approach taken is described in depth and the rationale for each stage of the approach is explained. This is supplemented by an example demonstrating the use of the approach. The whole approach has not been able to be tested on a real project through this research due to time restrictions. Therefore, opinions on the usefulness of the approach from a practitioner perspective have not been explored and this represents an area of future further work.

The next section discusses all elements of the Part 2 research in relation to the research questions defined through the literature review and considers how the work addresses these questions.

15 Part 2: Discussion

15.1 Introduction

This section discusses the work presented in Part 2 of the thesis and how it addresses gaps in the current research. It does this by considering the research questions, but also considering the results provided by the prototype decision support tool in comparison to the results of the case study project, which was undertaken before the development of the Roof DST. This demonstrates how it builds on existing research in these areas and also considers how it answers the research questions identified at the start of Part 2 of the research.

15.2 Overview of Part 2

Part 2 of the thesis builds on the reviewed literature undertaken in Sections 2 -4. The literature review on Sustainable Roof Selection (Section 3) originally considered *"what is a roof"* and *"why it is important"*. It considered historical methods of designing and selecting roof types and has demonstrated that with the globalisation of design methods and material use, there is now need for an approach to sustainable roof selection to support sustainable roof selection. It has also looked at the changing landscape of roof selection, from originally being required to provide primitive shelter, to now having to satisfy many requirements, such as increased thermal performance, attenuation of water, provision of biodiversity, etc. The literature review then considered more sustainable roofs and reviewed these options to gain an understanding of how roofs can positively impact on a development. The influence of roofs on environmental assessment methods, including BREEAM, LEED and Estidama were then considered, to understand how roofs can contribute to achieving high levels of performance under such assessment systems. The literature reviewed highlighted some gaps in knowledge with respect to informing sustainable roof selection, which led to further areas of work being identified for this research.

To consider the difficulties of informing sustainable roof selection on a real world project, previous approaches at informing more sustainable roof selection were considered on an action research based case study, where the researcher tried to apply techniques in the project context. This helped identify some of the limitations of the existing approaches and informed the development of a set of objectives for this part of the thesis, which were included in the introduction to the thesis. To address these objectives, Part 2 has developed an approach and a prototype DST to aid in making roof decisions with attributes relevant to the decision context.

The work described above is now discussed and reviewed in relation to the objectives defined for this part of the research. These objectives form the headings of this section. After summarising the work against these objectives, the contributions of this work are defined and further work with regards to this part of the thesis is then considered.

15.3 Review against research questions and objectives

The following section explains how the work addresses research question 2 and the associated sub questions which are as follows:

2. Is it feasible to develop an approach and decision support tool to inform roof selection that:
    a. allows the rapid definition and assessment of different roof systems?
    b. reflects the participatory nature of sustainability and allows for the consideration of stakeholder values?
    c. incorporates context specific locally-relevant information from research on roof performance?

These were defined based on the literature review as detailed in Section 5.2. The above questions are addressed through the four objectives as discussed below. These objectives also consider the objective *"to address the challenges of integrating sustainability into the design process in the building industry"* which was also an objective of Part 1 of the thesis. This objective was considered through the process of addressing the four other objectives associated with the above research question. Therefore, it is not discussed separately below, but is instead an integrated thread across all the work undertaken.

15.3.1 To define a set of attributes to assess roof performance

A set of attributes to assess the performance of roofs from a sustainability perspective were defined based on the review of the literature and the leading work in the field of understanding roof performance and informing roof selection. This included considering various roof types and their benefits including green roofs (Section 3.6.2 and Appendix L), “cool” roofs (Section 3.6.3 and Appendix M), solar technologies (Section 3.6.4 and Appendix N), and rainwater harvesting systems (Section 3.6.5 and Appendix O). Additionally, it considered three environmental assessment methods which included BREEAM, LEED and Estidama (see Section 3.4 and for more detail Appendix P) and how roofs could contribute to scoring points in these areas. This identified a list of common attributes discussed in the literature. This provided a list of 47 roof attributes that covered the different areas of a building’s life cycle. These attributes were then structured into a value tree and reviewed for completeness, operationality, decomposability, absence of redundancy and minimum size (Keeney and Raiffa, 1976). It was considered that the attributes were unlikely to be complete for all situations, the operationality was likely to be difficult as there was a large number of criteria, decomposability was also challenging as some attributes are likely to be difficult to assess independently of other attributes, there was a significant amount of redundancy and that the large number of attributes would probably mean that the decision making process was cumbersome. However, these areas were addressed, as it is considered a starting point of attributes that could be considered by the decision maker. Completeness should be considered on a project by project basis, and assessed accordingly. Attributes which were not included in the list could be added, however there is no consideration or guidance of how to get appropriate information on those attributes added by the user.

Operationality should again be considered on a project by project basis, however the operationality of the approach is improved as the decision support tool provides ways of getting the appropriate data on the attributes, through a combination of approaches, which include direct rating (for less scientifically developed attributes, or attributes which are more subjective such as aesthetics).

Decomposability, which requires that the attractiveness of a roof system on one attribute can be assessed independently of its attractiveness on another attribute, should be considered on a project by project basis. Attributes should only be selected if they are considered decomposable by the decision maker.

This also relates to redundancy, as redundant attributes are unlikely to be seen as decomposable. Potential areas of redundancy were highlighted diagrammatically by the author in Figure 14—36 to provide guidance for users of the roof decision support tool.

Whilst it should be noted that there are relationships between many of the attributes between the different EAM's of BREEAM, LEED and Estidama, they typically use different methods to assess performance. For example, whilst energy consumption and carbon emissions are often correlated, LEED utilises the US ASHRAE 90.1 Energy Standard against which to measure reductions in energy use with respect to *"EA 1 – Optimise Energy Performance";* whilst BREEAM utilises percentage reductions in CO_2 emissions against the UK Building Regulations Part L Notional Building to assess the points awarded for the *"ENE01 – Reduction of CO2 Emissions"* credit. Therefore, if the achievement of points against both assessment systems are relevant to the decision and both are therefore considered in the decision, then whilst roofs performing well on one of the above criteria are likely to perform well against the other one, the criteria should still be considered both redundant and decomposable.

Minimum size should be selected depending on the importance of the decision. It is unlikely that all 47 attributes are likely to be assessed at once, however more or less attributes may be appropriate depending on the importance of the decision and the requirements of the project and its stakeholders. A tool for assessing the importance of decisions is included in the decision support tool, covered in Section 14.2.1.

Whilst a set of 47 roof attributes are included in the decision support tool, other attributes can be defined by the user. This does not therefore restrict the roof attributes to be those that are included in the decision support tool already, these can be added to. However, in such circumstances, the user will have to score the performance of roofs and decide on how performance will be measured against those attributes. This could be simply accounted for utilising a direct rating scale. This question is considered to be answered by the work undertaken in this part of the thesis.

It is intended that the definition of roof attributes should be done through the application of Keeney's (1992) value focused thinking framework, considering the project level sustainability and value objectives, which may or may not be defined through engagement with stakeholders. The literature review and associated structuring of roof attributes meets the research objective.

Further work could consider the structuring of the objectives, in relation to strong sustainability criteria that places an emphasis on natural capital. For example through the TNS framework or the planetary boundaries as detailed in Sections 2.2.2.1 and 2.2.2.3.

15.3.2 To develop approaches to provide reliable, climate specific roof performance to inform decision making

One of the challenges of the design process as identified in Part 1 of the research, through the literature review and also specifically in relation to sustainable roof selection through Action Research Case Study 2A, was to provide information at the earliest project stages when it has the ability to influence the sustainability of the project the most. In order to address this question and align with the requirements of the design process, two methods of identifying the most appropriate information for attributes have been developed.

This includes a way of categorising leading peer reviewed journal research according to climate type, region and roof build-up to select the most appropriate green roof information quickly at the start of a project, which is described in more depth in Section 12.

Alternatively, where possible, leading and widely accepted modelling techniques have been applied to understand the performance of roofs on a range of attributes. This provides information quickly based upon the results of building simulation program codes and post-processing the output of such techniques to provide a single value on the performance of roof systems on an annual basis. This means that information can be rapidly acquired at the start of the design process, to be able to inform early stage decisions on a set of attributes that are widely discussed in relation to the impact roofs can have on typical sustainability issues. A structured approach has been developed such that the quantitative information on many of the attributes within the decision support tool are acquired automatically from modelling results based upon the attributes and roof systems selected by the user of the decision support tool. This therefore provides information quickly to provide indicative quantitative performance across a range of attributes. The developed approach is discussed in more depth in Section 13.

For subjective elements the user of the decision support tool can also directly score roof options utilising a direct rating method. This allows for roof options to be scored based on the opinions on the project stakeholders. This is particularly useful for considerations of aspects that are considered more subjective, such as roof aesthetics. This could be done in collaboration with project stakeholders, but if this is not possible, it would also be feasible for the user of the decision support tool to score this, as the results are then available for other stakeholders to see and critique if they consider these do not reflect the thoughts of the project stakeholders.

The combinations of roof systems was typically not considered by earlier work. The only other examples include the work of McCourt (2007) and Scherba et al. (2011). However, the work of McCourt was highly context specific and only considered a relatively small number of roof options. Additionally, whilst the work considered the application of combinations on top of one another; e.g. one *“water proofing and surface covering”* and one *“optional technologies”* to be mounted above the *“water proofing and surface covering.”* Combinations of several types of “waterproofing and surface covering” on the roof of one building and several types of *“optional technologies”* were not considered. The work of Scherba et al. (2011) considered the impact of the application of “optional technologies” on “water proofing and surface coverings” from the perspective of one attribute, which was the heat flux into the urban environment. This is a proxy measure to consider the urban heat island effect.

15.3.3 To develop a method which allows many different roof systems to be combined to consider the ‘roofscape’ of a project

The development of an approach and decisions support tool incorporates a simple method to account for different combinations of roof systems, by establishing either mono or multi-roof systems. A mono roof system is defined to be where the entire roof area of a building (the roofscape), is made up of one “water proofing and surface covering” and/or one “optional technology.” A multi roof system allows the application of many roof “water proofing and surface covering” systems and as many “optional technologies” as defined by the user. This research addresses this problem through allowing the user the ability to select the proportion of an overall roofscape for different roof system options and apply an area weighted average approach to defining the roof performance in relation to the selected attributes. This approach allows combinations of options to be assessed rather than just discrete options, and thus allows users to assess the potential of numerous combinations of roof systems across a building’s roofscape. This has addressed this research objective, and examples of combinations of options are given in the application of the roof decision support tool in the example context. Further work should assess how close this simplification is to modelling the options in a building simulation program, such as EnergyPlus. Recent work includes a macro-component approach for the assessment of building sustainability in early stages (Gervásio et al., 2014). This employs a similar approach to that detailed in this research for other building components, which allows a predefined set of library options to be swapped for a given climate. Testing has been undertaken and the error in the simplified approach when compared to the fuller modelling undertaken was approximately 4%.

Areas of further work would be to integrate a broader set of attributes to be able to broadly understand the performance against a wider range of issues. However, some elements such as the acoustic performance of roofs are difficult to understand, very context dependent, and will require consideration of the external environment. Therefore, this is likely to be significantly more complicated.

15.3.4 To develop an approach and decision support tool to aid decision makers in making more sustainable roof choices

Other decision making approaches to sustainable roof selection such as McCourt (2007), Nelms et al. (2007) and Grant (2007) have all focused on much narrower areas of selection with less focus on engaging stakeholders in the project environment to represent sustainability and value. This work builds on these approaches, bringing together several techniques, which include value focused thinking as an overarching framework, problem structuring methods for use in the construction context with stakeholders, techniques to gather the most relevant roof performance information and the SMART decision making technique as a way of weighting and bringing this information together to be able to assess performance in relation to roof related criteria.

When considering pluralist models with respect to forestry management, Mendoza and Prabhu (2006) and Mendoza and Martins (2006) consider that both traditional MCDA based models fail because of their rigidity and do not match the type and participatory nature of modelling in forestry management. Additionally, they argue that current methodologies are inadequate because they are inherently qualitative and do not offer a systemic framework by which natural resource management strategies can be evaluated. Both therefore have their limitations when used in isolation. They therefore argue for pluralistic systemic approaches to combine the notable strengths of the two methods. Other researchers have put forward rationales for mixing methods (Mingers, 2000, Mingers and Brocklesby, 1997, Howick and Ackermann, 2011). Howick and Ackermann (2011) reviewed 30 papers that have mixed OR methods. The benefits of mixing approaches include: improved confidence in the model, transparency in the process, decision makers engaged from an early stage, commitment to action, enhanced validity, greater support to creativity, and the methods mixed well in practice (Howick and Ackermann, 2011). The approach developed mixed several methods, to better define roof sustainability and value objectives, assess the performance of numerous roof systems and rank the alternatives, whilst considering sensitivity and risk.

There are numerous benefits to engaging stakeholders in decision making processes. The approach developed advocates engaging stakeholders to understand their broad sustainability and value objectives for the project through the techniques developed and tested in Part 1 of the research. The reason for this, is that project stakeholders are more likely to be interested in the broader project objectives. However, it is suggested that this project framing is used to consider roof objectives through the value focused thinking framework . Objectives, such as those defined through a literature review in this part of the research, which are made up of the 47 attributes. In doing so, it is intended that both a bottom up, community based and top down, expert driven approaches are used to decide on indicators. Again, mixing traditional approaches, which tend to be either expert driven or community based and advocating the approach defined by Reed et al. (2006) in the context of roof selection.

This approach utilises the SMART, a multi criteria decision analysis technique. Hajkowicz (2007) demonstrated that MCDA improves the decision process through better learning, clarification, transparency and accountability in the context of managing environmental problems for a region. Such techniques aid decision makers with respect to helping address the cognitive limitations of the human mind, which when decisions involve multiple objectives, resort to approximate methods to deal with decision problems. Such “bounded rationality” (Simon, 1982) means that decision makers often seek satisfactory rather than optimal courses of action. However, MCDA techniques are also considered to be open and explicit and allow the decision maker to better understand the decision situation (Goodwin and Wright, 2009).

In summary, the approach developed in Section 14 brings together many elements with regards to the French and Geldermann (2005) categorisation of methods, as shown in Figure 15—1, to develop a pragmatic realist approach to sustainable roof selection. This addresses gaps in the literature (see Section 5.2) and also the challenges of roof selection on a building project as defined through the literature review . This includes *"soft modelling"* through participation techniques to develop the decision objectives, as discussed in Part 1 of the research. The modelling of the performance of roof systems in a standardised format, as developed in Section 13, is considered a "forecasting" approach. A simple *"data-mining"* approach has been applied to merge information from the largest known green roof database and add additional data with respect to the climate of the site that the green roofs are located. This provides consideration of the risk of installing a green roof in such a climate type, by understanding how commonly done this is. This approach is further described in Section 14.2.7. Other performance information could also be determined to be retrieved from a data-mining approach, such as the merging of the green roof results of journal papers with the climate type of the region in which the results relate to. This is discussed in Section 12. All the above approaches are brought together through the approach developed, which is based on value focused thinking philosophy and SMART.

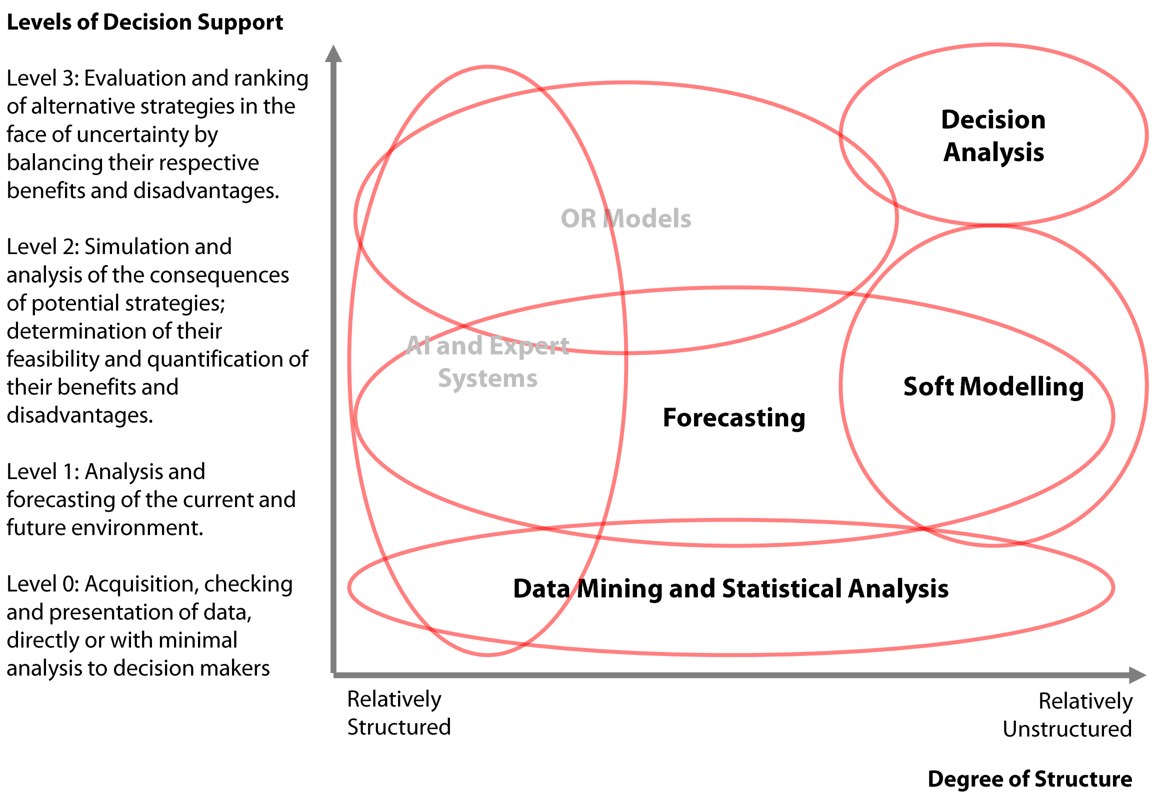


Figure 15—1 How various parts of the research relate to areas of decision making based on French and Geldermann (2005)

For most of the objectives included for selection in the prototype tool, the approach and accompanying tool has the ability to bring together standardised information on the performance of the roof types included, and also allow the rapid building of combinations of roof types into a 'multi-roof'. The suitability of this to informing roof design at the concept stage to inform decision making and design has to be tested and validated and this is suggested as an area of further work. An example with eleven different roof build ups, five of which were multi-roof is shown along with the results and how the information was obtained. This section includes a method that has been developed to consider the performance of different roof types based on leading modelling techniques. This includes the use of the EnergyPlus building simulation program and the "eco-roof" module, which is incorporated in the program. It outlines the standardised models utilised to assess roof performance for any region or climate type. The code was modified to be able to export the required variables and undertake any associated post-processing of results required in the Roof DST (See Section 13).

This complements a second approach developed in Section 12, which enables a decision maker to look up the most relevant research to a problem quickly, to inform the scores to be given to attributes relating to those outlined as important to roof decisions. This was highlighted as an area of further work by both (Grant, 2007, Nelms et al., 2007). However, neither the modelling nor the research classification method provides a clear way as to understand which roof option (or combination of roof options) offers the highest environmental, social and economic value across a range of attributes. This is why such approaches are integrated within the overarching approach to structure this information in an integrated manner through the Specific Multi-Attribute Rating Technique.

The decision support approach also includes a way of presenting information to the decision maker on the performance of numerous roof options in a simple and transparent manner. Additionally, all the data included in the approach and DST are referenced, and can be traced back to the various techniques used to acquire the data, providing an audit trail of decision making. Finally, the sensitivity of results can be analysed using sensitivity analysis. This can be useful when assessing the risk of different options. Additionally, the tool also incorporates a method of assessing other potential green roof projects, which are near the project of interest or in a similar climate type to provide case studies for reference and help provide the decision maker with a better understanding of risk.

15.4 Conclusion

This section has summarised Part 2 of the thesis and reviewed the various sections against how they address the research questions and objectives. The next section considers the overall conclusions to the thesis and identifies areas of further work.

16 Conclusions

16.1 Introduction

This section provides an overview of this research and reviews the work against the research objectives. The research process is then reflected upon and evaluated, through considering the reliability, validity and generalisability of the work. A critique of the methodology is then given before contributions to knowledge are then proposed and work to further develop the research outlined in this thesis is then considered.

16.2 Overview of research

The overall research aim was, *"To develop a pragmatic realist approach to sustainable roof selection in the context of building design"*. The research was then split into two parts and associated objectives defined for each part.

As the research is broadly based on Keeney's value focused thinking and in Keeney's words, "it is the values rather than facts where stakeholders can input into the decision making process", the research was split into two parts:

- Part 1: The development of approaches to engage stakeholders in defining sustainability and value for projects
- Part 2: The development of an approach and prototype decision support tool (DST) to inform sustainable roof selection

Part 1 has taken a values based approach to informing and determining sustainable themes for projects. These themes can then be applied to inform project decision making. The specific focus area of decision making considered in this research has been on the selection of improved roof systems. A roof decision support tool has been developed, which provides a structure and referenced set of techniques for providing information on the performance of different roof systems that consider the context of a project.

The concepts of value and sustainability have been discussed and a set of techniques for eliciting stakeholder values have been further developed based upon techniques found in the literature and to support the development of sustainability assessment techniques in areas which were identified to require further work in the literature. These techniques have then been applied in three case study projects. The feedback from stakeholders suggest that these techniques are useful in understanding the sustainability and value considerations for the group of stakeholders and identifying key themes for consideration in the project. These themes, although not further developed by this researcher, have been used to develop a project specific sustainability framework for influencing the design of the building, thus demonstrating that the engagement approaches were of value.

The development and testing of the engagement techniques demonstrate the feasibility of engaging stakeholders to define sustainability in the project context. This addresses a call for more inclusive and context specific consideration of sustainability in relation to sustainability in the building industry.

Part 2 addressed a series of sub-questions and objectives identified through the literature and practitioner experience through Action Research Case Study 2A. Approaches were developed to address some of the challenges. This included approaches for providing context specific and reliable roof performance information.

Additionally, a set of common roof attributes were identified through a review across the literature on the performance impacts of various roof systems. This provided a set of attributes against which performance could be assessed.

Then an approach to sustainable roof selection was developed that synthesised elements from the two parts of the research which is demonstrated with an example. This demonstrates how the themes identified through stakeholder engagement techniques can be used to help define the roof decision objectives for the particular project. This also considers other drivers, such as regulatory requirements and other widely used environmental assessment methods, which have been incorporated into the prototype roof decision support tool.

16.3 Review against research questions and objectives

This section briefly reviews the research against the original high level research objectives for both parts of the thesis and then considers the overarching objectives of the research. This is a summary of the more comprehensive review of the research questions that are in the discussion sections of both Part 1 and Part 2 of the thesis.

16.3.1 Part 1

The overarching research questions for Part 1 of the thesis were,

1. Is it feasible to develop stakeholder participation techniques to engage project stakeholders in defining project sustainability and value themes on which to base design decisions that integrates:
    a. stakeholder values and preferences?
    b. environmental, social, and economic value?
    c. stakeholder knowledge, rather than considering purely expert knowledge?

These were addressed through considering the objectives below. A fuller description is included in the discussion section of Part 1 of the thesis.

To develop and test a set of stakeholder participation techniques to define sustainability themes for a project's context

This was initially explored through the literature review, and key areas requiring further work were identified. This considered a review of techniques currently used in the construction industry, which primarily had an environmental focus, but also considered techniques such as the design quality indicator (DQI) and the value in design (VALiD) approach.

The approach takes a pragmatic realist perspective considering sustainability to consist of elements of positivism and interpretivism. In doing so, it acknowledges that there is a subjective element to sustainability and that like value, sustainability will be judged differently depending on the values of the stakeholders. It was also considered important to consider both sustainability and value together. Therefore, techniques such as the values based questionnaire (Schwartz and Mark, 1992, Mills et al., 2009), were further developed through action research to assess the values of the stakeholders of the group. By undertaking such an approach, whilst also considering the stakeholders' opinions on the various requirements of the group, the design team gains insight into what frames value for the group of stakeholders and use the knowledge to inform decisions.

Additionally, by asking stakeholders what they think represents a sustainable building from their perspective, it is considered that they will state things that they think are important and value. Thus aligning decisions to these key themes, provides a way of demonstrating how sustainable design features provide good value. Essentially, the approaches provide a starting point to frame decisions on projects. These themes can be further developed into appropriate metrics to inform decisions.

Workshop techniques were also developed and tested in Case Study 1B and Case Study 1C through an action research based approach. Themes emerging from a *"sustainable building is…"* session were considered by some participants and the client as good or high value design. The workshops also provide the opportunity for the design team to better understand the stakeholders.

Asking stakeholders to identify opportunities and constraints for moving towards a more sustainable building, brings into the process stakeholder knowledge and ways of strengthening opportunities to move towards a more sustainable and high value design. Workshop techniques, such as asking stakeholders what they think are the most important sustainability considerations, is also aiming to understand the priorities of the stakeholders and thus gain a better understanding of value from their perspective.

The *"importance vs. influence of the design team"* technique was useful for allowing stakeholders to consider the relationships between issues that they considered important and how much they could be influenced through the design.

Techniques such as the *"relationship mapping"* exercises, allow the stakeholders to see some of the inter-relationships between requirements, and that some indeed may be in conflict. Thus the delivery of all requirements may not be possible. Thus the approaches could be useful in managing expectations.

By taking the output content of the engagement techniques and using this to inform the definition of the key sustainability and value themes for a project, it is intended that these will be used to inform decision making. As stakeholders will then be able to see how different design options address these themes, it is hypothesised that the value of more sustainable design options will be more obvious to stakeholders. The timeframes of this research have, however, not allowed this to be reviewed and tested and this should form further work. A more in depth summary of how the work addresses the research objectives is provided in Section 9.3 of Part 1.

To address the challenges of integrating sustainability into the design process in the building industry

With respect to addressing the challenges of the design process in the development of the techniques for eliciting value, all the techniques were inspired by or developed from techniques in the literature, and discussed with practitioners within the sponsoring organisation before being tested in the project arena. All techniques presented here were utilised in a live project environment, the processes receiving good feedback from those involved and the outputs were considered useful by the design team, practitioners in the sponsoring organisation with respect to defining sustainability themes for the project's context. Therefore the action research based process of diagnosing, planning, taking action and evaluating in the context that the techniques are intended to be used was instrumental in meeting this objective. However, the literature review highlighted several challenges in the design process and these are considered below, along with how the techniques address such areas.

The techniques were developed to be used early in the design process to help address problems of the design team not being involved in the early project stages when the ability to influence sustainability is the highest.

Unclear or contradictory objectives and a lack of understanding of what represents good value were also identified as a challenge of the design process in the literature. The research addresses this by a combination of techniques. For example, the *"a sustainable building is…"* (Section 8.4.1) and the *"relationship mapping"* technique (Section 8.4.6) explore the definition of the key objectives, and also the relationships between objectives. Additionally, the *"value based project questionnaire,"* (Section 7.4.2) is aimed at understanding the values of the group and what stakeholders consider to be the most important requirements and subsequently aims to improve the knowledge of what is considered of value to the stakeholders of the project. The *"importance vs. influence"* technique is aimed at better understanding where the design team have the most influence to add the most value and thus explicitly communicate this to the design team. These techniques also help addresses the next related challenge, which was optimising performance against incomplete objectives.

Other issues included the fast pace of the design process which often led to a lack of integration and opportunities and trade-offs not being explored. The research addresses such issues through techniques such as the “value based project questionnaire”, which can be applied quickly to gain a wide variety of stakeholder opinions on what is important. This can identify stakeholder groups’ preferences and where there are discrepancies. This should help reduce decisions being made in isolation. Workshop techniques should also reduce the risk of isolated decision making through inviting a wide range of attendees to the workshops. Stakeholder mapping has not been discussed in this research, as it was not the focus of this work. However, this was considered for all case studies and should be conducted to ensure that relevant stakeholder groups are represented. The “relationship mapping” exercise is aimed at understanding the relationships between requirements and systems and opportunities and trade-offs at the start of the process. This aids group learning. Additionally, through mapping out the overarching objectives of the stakeholders, it is intended that the key themes can be considered by the design team as the design progresses. How the themes relate to specific decisions can then be considered by the respective disciplines.

Structured workshop techniques aim to improve the issue of a general lack of integration and communication between different stakeholder groups. Techniques such as “opportunities vs. constraints” aim to get stakeholders to feed in their knowledge on what could potentially be strengthened to improve the sustainability of the project and also identify constraints, so that ways of removing or reducing constraints can be identified.

The output of the engagement techniques also showed that this encouraged and allowed for consideration of issues throughout the design life of the building. The output of the workshops and the stakeholder participants were typically focused on the operational phase of the building and what would represent sustainability during this phase. However, aspects relating to the construction and even the transparency and robustness of the design process were considered by stakeholders through the workshops. It is considered that the objectives defined from the themes to inform decision making should cover the life cycle aspects of performance. This is further considered in relation to roofs in Part 2 of the thesis.

The biggest opportunity to influence sustainability is when there is typically the least information. This is another issue identified through the literature and also in Action Research Case Study 2A with respect to roofs. Whilst this particular issues was identified as an issue of the design process, it is not covered by Part 1 of the research, as there has been little focus on information and the assessment of options to inform decision making. This is however, considered in Part 2 of the research which looks at improving the speed at which quantitative information can be brought together to inform roof selection through approaches and tools developed. The development of the approach to sustainable roof selection, considered the challenges of design process as highlighted in Case Study 2A. The approach developed considered how roof performance information could be provided more reliably and structured to inform decisions early in the design process. Therefore, the development of the approach through addressing each of the objectives of Part 2 considered the objective *“ to address the challenges of integrating sustainability into the design process in the building industry”*.

16.3.2 Part 2

The overarching research questions for Part 2 of the thesis were:

- Is it feasible to develop an approach and decision support tool to inform roof selection that:
    a. allows the rapid definition and assessment of different roof systems?
    b. reflects the participatory nature of sustainability and allows for the consideration of stakeholder values?
    c. incorporates context specific locally-relevant information from research on roof performance?

These were addressed through considering the objectives below. A fuller description is included in the discussion section of Part 2 of the thesis.

To define a set of attributes to assess roof performance

This objective was addressed through initially reviewing the literature with respect to typically considered objectives that could be influenced by roof design and selection. This included considering various roof types and their benefits including green roofs (Section 3.6.2 and Appendix L), “cool” roofs (Section 3.6.3 and Appendix M), solar technologies (Section 3.6.4 and Appendix N), and rainwater harvesting systems (Section 3.6.5 and Appendix O). This was also accompanied by a review of three commonly used environmental assessment methods, which included BREEAM, LEED and Estidama (see Section 3.4 and for more detail Appendix P). These methods were selected because of their wide spread global use and also their interest to the sponsoring organisation for this research. This identified a variety of sustainability objectives in which roof design and selection could influence. These were structured in the development of an approach and decision support system into a decision tree as shown in Section 14.2.2. It provides a list of 47 roof sustainability objectives defined from the literature against which the performance of a roof can be defined. Whilst these are provided as a set of roof objectives to assess performance, the approach to sustainable roof selection and accompanying decision support tool provides a method of also adding additional attributes, and allowing the user to assess performance using a direct rating technique.

Additionally, an approach developed advocates considering how the roof performance attributes align with broader project sustainability and value themes through the value-focused thinking framework as defined by (Keeney 1992). The sustainability and value themes could be defined through applying the engagement techniques developed in Part 1 of the research.

To develop approaches to provide reliable, climate specific roof performance to inform decision making.

This objective is addressed in Sections 12 and Section 13 which develop approaches to providing reliable, climate specific roof performance information. The approach and prototype roof decision support tool that have been developed incorporate these two approaches for providing the most reliable performance data for a variety of roof system types. These include a method for categorising and looking up the most relevant research for green roofs based on climate type. This provides structure to help the user of the decision support tool identify the most appropriate information to input into the decision support tool.

The structure proposed provides a quick and simple way of identifying reliable green roof data to inform sustainable roof selection. This is addresses requirements with respect to the need for quantitative information at the start of a project where information is typically limited. Additionally, the approach developed in Section 12 collates existing research and identifies climate and roof types which would benefit from future study. Approaches to quantifying the performance of different attributes are also considered in Appendix L to Appendix Q.

To develop a method which allows many different roof systems to be combined to consider the ‘roofscape’ of a project

Until now, no approach to decision support has had the ability to be able to rapidly assess different combinations of roof options against a significant set of attributes. Focus has previously been limited to just one or two roof attributes and a relatively small number of roof systems. This research addresses this problem through allowing the user the ability to select the proportion of an overall roofscape for different roof system options and applying an area weighted average approach to defining the roof performance of those attributes (see Section 14.2.3). This approach allows combinations of options to be assessed rather than just discrete options and thus allows users to assess the potential of numerous combinations of roof systems across a building’s roofscape. This has addressed this research objective, and examples of combinations of options are given in the application of the roof decision support tool in the example covered in Section 14.3.3.

To develop an approach and decision support tool to aid decision makers in making more sustainable roof choices

More detail is provided on how the research meets this objective in Section 15.3.4. This involved development and synthesis of numerous decision support methods developed through this research as shown in Figure 15—1 to inform sustainable roof selection, this draws on techniques from both parts of the thesis.

Part 1 provides a set of techniques that can be used remotely via questionnaires or in person through a workshop, to establish the sustainability and value themes for a project's context. The techniques also help to provide the design team and stakeholders with an understanding of the opportunities and constraints for a project, an initial consideration of importance, and also the relationships between different considerations. In doing so they help develop an understanding of the sustainability objectives of the project within a particular context. These techniques are summarised in Section 9.2 and can then be used to help inform the more detailed objectives with respect to making project decisions.

Part 2 then develops an approach and decision support tool for informing sustainable roof selection. Through the value focused thinking framework the output of the techniques developed and applied in Part 1 of the thesis can be used to help inform the selection of the objectives against which different roof options can be assessed. Additionally, some of the output of the engagement techniques could also be useful in informing the weightings of the decision objectives. Part 2 also provides a way of obtaining relevant information quickly for many aspects of roof performance (Sections 12 and 13). Speeding up the process of collecting performance information helps inform decisions used in the earliest stages of design. This addresses one of the many challenges of the design process when considering sustainability as detailed in Action Research Case Study 2A (Section 11). Other challenges are considered through Part 1 of the thesis. The application of the decision support tool is considered through an example which is covered in Section 14.3.

The overarching research aim was, ***"to develop a pragmatic realist approach to sustainable roof selection in the context of building design."*** Through addressing the objectives in Part 1 and 2 and considering how these can be integrated, the above research objective has been met. The contributions to knowledge are detailed in Section 16.7, before a brief summary of the areas of further work are detailed to address some of the limitations of this research.

The next section provides a reflection on the research process.

16.4 Reflection on research process

Through this research, the researcher has utilised a range of research techniques and data collection methods and refined his skills in these areas. This has provided the researcher with an excellent opportunity to develop his knowledge and application of research methods in the industrial setting. For the duration of this research, the researcher worked and was located within the sponsoring organisation and thus adopted the role of the practitioner-researcher (Saunders et al., 2003). This has many benefits, which are described by Saunders et al. (2003) as a good understanding of what goes on in the organisation and the industry and less time required in "learning the context". However, as a consequence of knowing the organisation well the researcher (Saunders et al., 2003):

- must be very conscious of the assumptions and preconceptions that they carry around with them
- is less likely to ask basic questions because you and your respondents may feel that you should know the answer to the questions
- should consider the problem of status, for example in the case of this research, the researcher was a junior member of the sponsoring organisation
- will have to address the practical problem of combining two roles at work and the limitation of time

Whilst, Robson (2002) and Saunders et al. (2003) note that there are no easy answers to the above problems, the researcher was aware of these potential problems and the impact that these could have on the quality of the data obtained through the work.

The overarching action research methodology that was adopted was to first, understand the industry through applying and discussing techniques internally within the sponsoring organisation; then to discuss and develop techniques in collaboration with those in the sponsoring organisation. This allowed me to gain the trust of the senior individuals that was required in order to undertake these techniques in a client setting. This has also had industrial impact bringing techniques, which were not known to the other practitioners involved in the research, into the industrial setting. In the opinion of the researcher, the action research process was extremely important in being able to investigate the definition of sustainability with project stakeholders, whilst ensuring that the practitioners of the sponsoring organisation were comfortable with the methods being used.

At times, the practical setting of the research has been both a curse and a blessing. A blessing in that the research was grounded in the industrial context. However, sometimes frustrating in that certain changes had to always be made to reflect the project's context. For example, with Case Study 2A, the workshop ideally would have been longer, but it was not possible to access the required stakeholders at the same time for a longer period of time during the required stage of the project.

The researcher also considers that his inexperience in the industry has, at times, limited the speed of progress of the research. For example, it is not typical for a person of the practitioner-researcher's age and experience to be running and facilitating client and stakeholder facing workshops, which are typically not the norm in the industry. Therefore, a significant investment of time was required within the sponsoring organisation to convince the required people of the value of the approaches, which had not yet been tested in the project context.

Additionally, the skill and experience of a facilitator is noted extensively as an important aspect to stakeholder engagement (Reed 2008). The researcher had to develop these skills within the sponsoring organisation through the action research process in a short period of time. Additionally, as numerous facilitators were required for the action research case study projects, the facilitator had to familiarise the other facilitators with the approaches in a very limited period of time. The fact that the feedback from the workshops was generally positive was despite the limited experience of the facilitators.

Actions research Case Study 2A, which considered roof selection on a real world building project, really highlighted the challenges of informing roof selection in the industrial context. Project deadlines were never far away and there simply wasn't time for the researcher, who had a good understanding of the performance of roof options, to bring together information in a manner that would have allowed the reliable ranking of alternatives. This also highlighted the numerous limitations with previous approaches, which had not been developed and tested in the industrial context. Whilst it is noted that the challenges faced here cannot be generalised across every project in the construction industry, it was considered a good starting point for the development of the approach and accompanying decision support tool to inform sustainable roof selection.

This highlighted the need to be able to acquire relevant context specific data quickly, for a particular region and roof type, was extremely important with respect to roof selection. Whilst, it was clear from the literature review that much information was available, there was no overarching approach to categorising this information with respect to green roofs and no way to locate research data easily. Therefore, Sections 12 and 13 are concerned with how to do this utilising the existing research information and the latest modelling techniques in a structured manner. It was considered that by going through this process, the work was being made more accessible to industry through providing improved clarity on the generalisability of the research to a particular context. Additionally, it was useful in highlighting regions and climate types with gaps in the current green roof performance literature.

The development of the approach and decision support tool for sustainable roof selection involved bringing together various aspects of the research into an overarching approach. It builds on outcomes of the Action Research Case Study 2A and the challenges of the design process also highlighted in the literature review (Section 2.3.3). This considered how techniques developed to quantify the performance of roofs could be integrated to provide ranking of alternatives through decision analysis techniques. This utilised techniques developed in Section 12 and 13 to quantify performance and also drew on many commonly discussed roof performance attributes, as a starting point for quantification of performance. Simple techniques were also developed to be able to quickly “build” numerous roof options, which may be of interest to the stakeholders.

Keeney’s (1992) VFT is then utilised as a framework to consider the roof objectives within the wider strategic objective framing of the project objectives. This is considered to offer both a bottom up and top down approach to the selection of roof objectives and associated attributes.

Then roof performance, considered through a variety of means but including approaches developed in Sections 12 and 13, needed to be considered through the specific multi-attribute rating technique. This involved the researcher learning skills from several different disciplines, which included the ability to modify Fortran 90 computer code and write VBA code, to get certain performance attributes out of the modelling process in a structured way, which could then be analysed statistically for decision making. Risk and sensitivity is considered through an approach, which involved combining information from two datasets to provide better information on the risks associated with the installation of green roofs in particular climate types. The approach, whilst not tested on a real life project, was demonstrated through considering a case study project. Further work will involve testing this in the project context.

It is considered that there has been significant contribution to practice through the research. The next section discusses the contribution made to theory, by first critiquing the methodology and then evaluating the research with respect to validity, reliability and generalisability. Something that other techniques aimed at informing roof selection have not done explicitly with the exception of Grant (2007) who briefly touches on generalisability.

16.5 Critique of methodology

In this research a range of techniques were brought together, in an attempt to define an approach to sustainable roof selection that brings together the performance of different roof systems, with the elements of a project considered of value and sustainable by stakeholders. However, only constituent parts of the process have been tested; the techniques identified with respect to defining project objectives have been used with positive feedback from numerous sources as part of the action research process. The development of the techniques was undertaken in collaboration with industry stakeholders inside the sponsoring organisation and developed before being applied on projects. The techniques were developed to consider the challenges of the design process, which include limited contact with project stakeholders.

Time limits on the EngD duration have meant that the whole approach has not been tested in its entirety on real world projects. There was not opportunity for trialling on projects and thus opportunities for feedback on how the whole process can improve the selection of more sustainable roofs in a given context is an area for further work.

However, testing of the usefulness for industry through several techniques to assess the approach would be beneficial and this could include interviewing a range of practitioners from different backgrounds within the industry to consider how useful they considered the decision approach and tool to be. This would provide improved validity through triangulation of sources.

It was not possible to undertake a long term assessment of the outcomes of the process due to the bounded timescales of the EngD research.

Testing the effectiveness of the techniques developed in comparison to more established techniques of PSMs was not possible in the timeframe of this research. Therefore, questions such as, “were the approaches developed and used in this research more effective than existing approaches?”, is not possible to state with confidence.

The action research was iterative in nature in that the techniques were developed in collaboration with people in the sponsoring organisation and refined through feedback from application on client projects. However, undertaking more cycles of the action research process and incorporating learning into future cycles of action would have been beneficial.

With respect to the synthesis of Part 1 and Part 2 areas of further work have been identified through a number of noted limitations of the work. These include:

- The testing of a set of participation techniques on only a limited number of stakeholders and projects through the action research based approach.
- Not being able to test the whole decision making approach with engagement from stakeholders. The research only tested component parts of the tool and not the whole approach to decision making on a real project.
- The limited triangulation of data sources. The research would have benefited from improved triangulation of data sources. For example, although surveys were undertaken to understand how well sustainability perspectives had been captured, further follow up interviews would have offered improved triangulation and improved the quality of the research. This would have provided an additional check to ensure that the themes that emerged from the analysis of the content of the workshops were representative of the thoughts of the group, as demonstrated in other work such as Tippett (2004).

16.6 Evaluating the research

In evaluating this research, it is important to note that the literature regarding problem structuring methods, is at this very moment debating how to best evaluate the success of methods and also trying to develop approaches to do this from different philosophical backgrounds. Evaluating the success of problem structuring methods is an area identified as further work by Mingers and Rosenhead (2004). This is a view shared by Ackermann (2012) who explains that there is a concern regarding the lack of empirical evidence of effectiveness of PSMs. Whilst Mingers and Rosenhead (2004) argue that their growing use and repeated use provide prima facie evidence for their efficacy, but ask the question is it possible to measure their contribution more rigorously, for example through comparing using a PSM against not, or comparing PSMs with each other. They conclude that this is a difficult question to answer. Checkland (1981) argues that it is not possible to meaningfully measure the effectiveness of a particular use of a methodology as every instance of use will be unique, inextricably bound both to the problematic situation and to the users of the methodology. He says,

> *“If someone says to me: “I have tried the methodology and it works’ I have to reply on the lines: “How do you know that better results might not have been obtained by an ad hoc approach? If, on the other hand, the assertion is “Your methodology does not work” I may reply, ungraciously but with logic “How do you know the poor results were not due simply to your incompetence in using it?”* (Checkland, 1981, p241).

However, depending on your underlying philosophy, some may argue that their processes have a high degree of internal rigour, and that it is based on theoretical and philosophical grounds (Mingers and Rosenhead, 2004). However, others would argue that validity requires comparative experimental testing through the use of formal laboratory and field experiments (Finlay 1998). However, this assumes a particular method can be abstracted from its context of use and compared in a controlled environment (Mingers and Rosenhead, 2004). Mingers and Rosenhead (2004) state that:

> *“Most developers of PSMs would ally themselves to an interpretive paradigm and argue that each particular real-world application of a PSM is, in most ways, a unique event that can only be evaluated in its own terms.”*

Another reason why the effectiveness of PSMs is hard to judge is that with policy or strategy work, the effectiveness and the validity of the outcomes is hard to determine as it is impossible to run the experiment again (Ackermann, 2012). Vidal (2004) recognise the plurality of views, and states that in the OR community there is no consensus on how to evaluate PSMs and there exists a range of approaches and claims, each with its own strengths and weaknesses.

However Mingers and Rosenhead (2004) state that there are some ways of measuring perceived effectiveness of PSMs. This has been done through reviews of practitioners own interventions as detailed in Connell (2001) and Ormerod (1996). Interestingly Connell (2001) considered that the use of SSM in helping design an information system for the UK NHS was a failure because it did not result in an implementation of the recommendations. However, a later review concluded that the original project was generally seen as successful in generating insight and a degree of consensus, but not sufficient commitment among the participants to breakdown long-standing disciplinary boundaries. In Omerod (1996) the practitioners returned several years later to check on the development and success of the projects recommendations. Whilst the project had gone over budget the benefits of the system had also been understated and the management considered the project important both in its outcomes and in learning gained during the process. In the above two examples, surveys asked respondents (users or practitioners rather than clients) how successful they believe the methodologies were. With respect to Connell (2001), 64% rated the level of success as “good” or “very good” and only 6% as poor or very poor. When asked about the practicability 35 of the 65 gave an unqualified yes and a further 26 gave a qualified yes. Again, very few answered negatively. Again, in the survey of Omerod, on a 7 point scale, to rate the mean success rating for the individual PSMs and related methods, the response was generally marked over five. This discussion highlights some of the challenges in defining whether PSMs are successful or not.

When claims are made regarding the success or failure of problem structuring and other participatory methods, reviews show that most of the justifications provided by researchers are based on personal reflections alone (White, 2006, Rowe and Frewer, 2004, Midgley et al., 2013, Connell, 2001). However, this research goes beyond that to include the thoughts of the participants’ consideration (after workshops) of the outputs and of the approaches, and also through providing the opportunity to feedback.

Recently, Midgley et al. (2013) have developed a framework for evaluating systemic problem structuring methods. From their review of the literature they state that it is clear that only a very small minority of studies seek to compare between methods or across case studies undertaken by different researchers. Through this they propose four key areas of, context, purpose, method, and outcomes. For each element of the research, each of the above four key areas was explained, thus allowing other researchers the ability to understand how the outcomes relate to context, purpose and method.

In developing an approach to evaluation of PSMs, Midgley et al. (2013) trialled the use of a questionnaire. Their paper demonstrates the difficulties of judging the success of PSMs as they are used in the real world environment and through observations of participants completing the survey it was judged to be too long. Thus, it was shortened, but then this led to some important data gaps. In the end they compromised between comprehensiveness and brevity and in doing so waivered some rigour in favour of relevance. What approach they use to “judge” is not specified and is assumed to be subjective judgement. This is not a criticism of their work, but just highlighting that gaining objectivity in assessing the effectiveness of PSMs is a battle of two paradigms, interpretivism vs. positivism. Additionally, their survey is also caveated, stating that the quantitative data generated through the questionnaire, on the process and short term outcomes always has to be interpreted in relation to other aspects of their framework, including context, purposes, longer term actions and research skills and preferences. All of which have numerous possible ways of categorising.

Midgley et al. (2013) also state that the limitations of the approach, could be that the researcher could avoid unwelcome conclusions, for example through placing too much emphasis on a nature of context that they had no control over. However, there are methodological aspects in the survey device that endeavour to avoid this, which involves (1) the questionnaire enables participants to have a say including through open ended questions which allow participants the ability to state why they think there are short comings, (2) by offering guidelines to consider context through multi-paradigms, the risk of “paradigm blindness” is minimised; (3) by focusing attention through the approach on the researchers identity, purposes, outcomes, skills and preferences, the framework confronts practitioners with questions that they might like to avoid.

Another limitation that is considered by Midgley et al. (2013) is that, through utilising the survey to potentially compare the use of methods over time, is that there is a growing movement towards multi-methodology (Jackson, 2000, Mingers and Brocklesby, 1997, Mingers, 2000). Midgley (2000) c.f. Midgley 2013, states that multi-methodology, "at its most flexible, pluralist practice, may involve the integration of several previously distinct methods into a new whole, perhaps also incorporating the design of novel elements." It follows that it will be much easier to compare standard sets of established methods than it will be to compare multiple methods in combination that have not been widely applied. They state that the irony is that the more flexible that their approach is made to account for this, the more difficult it will be to compare methods over time in a manner that can control contextual effects. Additionally, they state that they would not want to see the desire for improved evaluations result in the stultification of pluralist practice.

Additionally, whilst the survey offers an approach to evaluation within the context, it is also designed to be used comparatively with other studies to be able to understand the successes of different interventions in comparison to each other over time. Unfortunately, at the time this action research was undertaken, this survey was not available and instead the researcher developed their own survey to assess the success of the workshops for case studies 1B and 1C. Whilst the results were generally positive, with a few suggestions for improvement, there was little evidence of such techniques being applied within the context of construction projects, and of those that were, no examples were found of quantitative or qualitative feedback from the participants on the efficacy of the techniques. Therefore, no comparison was able to be made as to whether they were more or less effective than other techniques.

As this research has taken a pragmatic realist multi-method approach in a bid to minimise paradigm blindness, the next sections considers the reliability, validity and generalisability of the approaches used and reflects on how the work can be further developed in the future.

16.6.1 Reliability

Reliability refers to the extent to which data collection techniques or analysis procedures will yield consistent findings. It should consider (Saunders et al., 2003):

- Will the measures yield the same results on other occasions
- Will similar observations be reached by other observers
- Is there transparency in how sense was made from the raw data

From a positivist perspective this is concerned with whether another researcher could gain the same results through undertaking the same methods in a controlled experiment. However, in the case of this research, it is considered that the exact conditions of any of the action research process could not be re-repeated. The research itself, with involvement of practitioners in the sponsoring organisation to refine and test methodologies, creates change. Checkland and Holwell (1998) argue that whilst the laboratory research in natural science can stop when replicable results show that a hypothesis has been refuted or has survived the tests to which it has been subjected, action research accepts that social phenomena are not homogenous through time. Thus the end of a piece of research in an organisation is ultimately an arbitrary act.

The application of some of the same methods on different projects, as done in part through the action research process undertaken on Case Studies 1B and 1C, demonstrates the application of the techniques yielded different results. However, it is argued that this reflects the different context of each project, including different stakeholders, with different values and a different purpose for the building. Checkland and Holwell (1998) argue that any organisational situation at a particular time, with its particular participants having their own individual or shared histories, may be unique, it cannot be guaranteed that results can be made richly meaningful to people in other situations. In fact it is argued this highlights the very need to undertake such stakeholder engagement approaches to define what economic, social and environmental considerations are important within the context, rather than try and generalise a standard set of considerations across a myriad of projects as is the case with many environmental assessment methods such as BREEAM. This is in fact what is critiqued by many authors as a failing of traditional environmental and sustainability assessment methods within the construction industry, which have a more positivistic approach aimed at generalising results across many projects and ignoring the local context.

Checkland and Howell (1998) propose the concept of recoverability in place of reliability. Recoverability is concerned with whether the process is recoverable by anyone interested in subjecting the research to critical scrutiny. This requires explicit discussion of the framework of the research, its aims and methodology used so that interested parties can recover the process of the research.

With respect to recoverability, the aims are defined through research questions and objectives defined in the methodology, additionally the methodologies and data collection methods are explained and there is also transparency in the way sense was made from the data. This included reports circulated back to stakeholders based on their responses to survey questions or the content they generated in workshops. Workshop content was all documented using photographs and the material was collected and transcribed after the workshops (with the exception of Case Study 1A, where the follow up workshop was used to primarily present back results and gain feedback on whether the questionnaire based approach was useful). The coding and theming was also included in the appendices to reports so that for each piece of content, stakeholders could see how comments had been coded.

Midgley et al. (2013), with respect to testing a questionnaire to consider the success of problem structuring methods, state that reliability is hard to test with respect to surveys as it involves asking participants to fill in the same questionnaire on two separate occassions and generally speaking the researcher only has access to the participants on the day of the workshop. They therefore state that their method of assessing the success of PSMs is not necessarily reliable

Midgley et al. (2013) are essentially evaluating their evaluation method and discussing the difficulties of doing this. To some extent this also highlights some of the problems to do with testing the reliability and validity of techniques used in workshops and participatory techniques. Ideally from a positivist perspective you would want to conduct the approach utilising many sets of project stakeholders who are the same, in the same project context, with the same techniques and see if you get the same outputs and outcomes to test for reliability. However, in the context of a controlled experiment this is difficult and the fact that the participants would be removed from a real context would also impact on how the participants interacted with the situation. Within the context of a real building project, as in the case of this research, it is argued that this is impossible due to practical issues, such as time and money constraints. Even if funding was available, the ability to get similar groups of people, discussing the same project would be an extremely challenging process.

With respect to the secondary data sources reviewed and categorised to quantifying roof performance it is assumed that the techniques of the field/lab experiments and modelling techniques referenced are reliable. However, this is not typically discussed and as noted in Section 12.4, the repeatability/recoverability of some of the experiments is questionable as information on the roofs tested is not clear. This also has implications in terms of generalisability. Additionally, when attempting to undertake the modelling approach detailed by Scherba et al. (2011), the researcher was unable to obtain the same results for some roof types. Therefore, further work could involve replicating the work of others to test for reliability.

16.6.2 Validity

Validity is concerned with whether the findings are really about what they appear to be about (Saunders et al., 2003).

In Part 1 of this research, data from the process was generated with stakeholders. Originally, techniques were reviewed and selected based on theory from the literature, and then trailed internally, before use externally as part of the action research methodology. Brydon-Miller et al. (2003) explain that, *“one of the tenets of action research is that research that is conducted without a collaborative relationship with the relevant stakeholders is likely to be incompetent. The respect action researchers have for the complexity of local situations and for the knowledge people gain in the processes of everyday life makes it impossible for us to ignore what the ‘people’ think and want.”* Brydon-Miller et al. (2003) go on to argue that, *“action research is more able to produce ‘valid’ results than ordinary or conventional social science because expert research knowledge and local knowledge are combined and because the interpretation of the results and the design of actions based on those results involve those positioned to understand the processes: the local stakeholders.”*

Additionally validity was considered in the research design, through asking participants in the research to feedback after the results of the data collection method were communicated. This was done in a workshop format for the questionnaire circulated in Case Study 1A. Asking participants whether the results reflected their opinions. On the whole they were considered to be reflective, with minor corrections with respect to the wording of some of the questions leading to some results that would not be expected. However, whilst this method was triangulated through the workshop, it should be noted that the questionnaire, was derived from the brief for that particular project, and it is suggested that such a questionnaire whilst having questions relating to the generic values, according the Schwartz values continuum, it should also ask project specific questions, which could be derived from a brief. The approach and the results therefore will yield different results each time, as both the questions and the context will change.

Testing for validity is considered difficult and is discussed in Rowe et al. (2005). One of the reasons being that in the field participants are often reluctant to fill in two or more questionnaires asking similar things (which is the usual way to validate a questionnaire).

In the case of Case Studies 1B and 1C a summary of the main themes emerging from each workshop session, were summarised by the facilitator for each group to the rest wider groups during the session, with participants being asked to add things that they thought were missed or incorrect. Additionally, the results of the sessions were summarised in a report. Respondents were encouraged to feedback if they considered that something of key importance had been missed. Further testing was incorporated through feedback questionnaires immediately after both the workshops. Feedback immediately after the workshops was generally positive, with stakeholders saying that the approaches had managed to capture the sustainability perspective of the group in today’s workshop. An additional question added to the survey for the second case study demonstrated that participants were comfortable sharing their opinions.

An approach such as asking similar purposes questions was undertaken in Workshop 1B, that sought to see if the techniques were reliable, i.e. through getting participants to complete similar exercises to see if similar results were obtained were seen by some participants as repetitive and the researcher through observation at the workshop got the sense that some participants were frustrated by this as discussed in Section 8.7. Therefore such approaches were not considered appropriate in Case Study 1C.

In the Case Study 1C, a series of three workshops were utilised to first introduce the techniques, then to undertake a workshop to capture their thoughts on sustainability, and finally to playback and review the output of the workshops. Stakeholders were asked to feedback if they thought the outcome of the reports didn't reflect their thoughts as a group, however no comments were received in relation to this. They also had an active reason to do this, as the projects were both live and thus misinterpretations may have had real implications for the project.

With respect to whether the techniques were able to overcome the challenges of the design process, the success was partially supported by the fact that they were developed by practitioners with knowledge of the design process and also applied on real world projects.

In addition to this, the approaches to and data generated from the workshops, were presented to many different academics and practitioners, with the opportunity for feedback. This included the global executive of the sponsoring organisation, and numerous group sessions with teams and individuals within the sponsoring organisation, including numerous senior staff at director level. Comments from these different presentations and discussions were considered in the analysis.

The approaches have been presented numerous times to more than 100 individuals within the sponsoring organisation, with people explaining that the approaches and the outputs that they provide would be really useful for use on projects they are working on. The interest shown in the research by the sponsoring organisation offers an indication that the approach is seen as useful. The future work identified as part of this research, which will involve further testing on a broader number of projects with a wider array of project teams, will provide a further indication of the value of the approach and work. Since the case studies have been conducted, further projects have used the approach with successful feedback from client stakeholders.

With respect to the overall process proposed through this research, which connects identification of project sustainability requirements with roof selection, further work is required to test the validity of the overarching approach on projects. However, the theory of how the approach could be applied and a discussion of its usefulness is presented in the thesis through application on a case study project.

A summary of approaches to ensuring validity were also taken and are included in Table 16—1.

Table 16—1 Methods used to enhance research validity

Method	Where included in this research
"Thick description" of context as defined by (include references)	In depth description of context, purpose, methods, and outcomes
Careful and rigorous coding of data	Data from workshop that was coded, was done so rigorously and transparently and also reviewed prior to being circulated back to participants in a write up to workshop
Peer review	Interim findings were presented back to members of the team, including project managers, and stakeholders in Case Study 1C. Additionally, the processes used, and the outputs from the processes were more widely presented in the sponsoring organisation, with opportunity to discuss and critique. The techniques and outcomes were also presented at conferences
Participant Checking	Participants were given the opportunity to check the output of the workshops and were encouraged to feedback if they felt it wasn't representative.
Triangulation of data sources	There were several different data sources - Internal trial questionnaires - Internal exploratory workshops with engineers - Workshops to discuss results of questionnaires - Participant observation of the workshop process - Workshop discussions - Feedback forms from workshops Dialogue with other consultants in the process
Prolonged engagement with stakeholders	The work was undertaken over the course of a five year period with the research immersed in the organisation. The action research process was applied and there was a continue cycle of diagnosing, planning, taking action and evaluating over this period. Three case study applications of varying approaches were undertaken in this period.

White (2006) argues past focus on the approaches to evaluation placed too much emphasis on satisfying validity claims and often neglected paying attention to what works, for who and in what circumstances and in doing so White takes a more pragmatic approach to evaluation. Additionally, there is significant argument based on the ways to judge the success of an intervention based on the paradigm from which different authors take. For an example with respect to group decision support in design see Reich (2010). White (2006) argues that this polarisation advocates taking 'purist' positions and spurning methods that could enhance their own evaluation practices. Instead he considers evaluation has to be pragmatic and therefore posits two aims of the evaluation in his paper, (1) describe what happened during the intervention and to understand how and why certain things happened or did not happen, (2) to carry out further reflections of the findings in order to provide some insights in order to develop 'middle-range theories' that could provide guidance about other similar interventions. The intention of the evaluation was to assess the effect of the PSM interventions on the outcomes, rather than provide a description of the process of the intervention. However, in doing so, he undertook a significant evaluation of a problem structuring intervention, which involved:

1. exploring theories in use in terms of PSM interventions
2. collecting data through a pragmatic combination of approaches
3. coding and analysing the data using a qualitative software package
4. constantly reviewing findings with stakeholders

This was conducted in two phases including;

- preliminary phase of literature review and personal reflections
- evaluation phase including,
    - pre-intervention stage interviews and group discussions
    - intervention stage involving observation of the processes, reviewing the models and artefacts produced, interview and feedback from the participants
    - post-intervention stage interviews and group workshops.

With respect to the evaluation phase, the evaluation strategies listed above involve a considerable amount of work and require significant stakeholder buy-in to the process to be achievable. A preliminary literature review and personal reflection was undertaken, and intervention stage observation, reviewing of models produced and feedback from participants was also undertaken. However, pre-intervention and post-intervention interviews with participants would have further improved the validity of the work. However, such time consuming work was not possible in the time frames of this research. Additionally, in the case of interventions with respect to the design and construction of buildings, it is likely that such evaluation techniques would take longer than the process themselves and could not be carried out repeatedly as part of standard practice. Midgley et al. (2013) agree with White (2006) that a pragmatic step sideways is required from the 'either/or' debate of positivism vs interpretivism. However, they argue that identifying effective evaluation methods requires considering the practicalities of undertaking evaluations as well as the norms of what constitutes a valid or legitimate methodology. In doing so a balance has to be struck between rigour and relevance (Shaw, 1999). If this balance is not considered then there is evidence that stakeholders will not co-operate (Rowe et al., 2005).

It is considered that this work, being set in the industrial context, has had to balance this carefully. For example, whilst Midgley et al. (2013) have developed a survey as part of an evaluation process for PSMs, it was considered too long in the trial as detailed in Section 16.6. Thus it was made shorter, but then notable gaps in data were evident. The survey developed by Midgley et al. (2013) was not used on any of the case study projects to judge the success of the PSMs, as it was not available at the time. However, a short survey was used by the author to ask the participants whether the sustainability perspective of the group had been captured and whether they thought the techniques were efficient and effective. The response rate for both projects was 50% (Case Study 1B) and 39% (Case Study 1C) and thus the response rate was already low. The author's survey was significantly shorter than that of Midgley et al. (2013) and it is considered that a longer survey, may have had an even smaller response rate. Additionally, Midgley et al. (2013) state that the reliability and validity of their survey, has not been tested and state the difficulties of doing this. Therefore further work, specifically on the evaluation of PSMs is considered necessary.

With respect to the validity of Part 2 of the research, all data utilised in approaches was from peer reviewed journal papers, or widely accepted industry used techniques.

16.6.3 Generalisability

Generalisability refers to whether the research findings may be equally applicable to other research settings (Saunders et al., 2003).

This researcher shares the assumptions made by most of the creators of PSMs in that knowledge created is always linked to the purposes and values of those producing or using it (Jackson 2006). To claim that knowledge is universal is to ignore the purposes, values and boundary judgements that make the knowledge relevant and adequate for a particular context. Additionally, as argued by Midgley et al (2013) claiming universality for knowledge would suggest that this knowledge will remain stable over time, but new problem structuring methods are being produced on a regular basis. This suggests that people are learning from previous practice and are also having to respond to an ever increasing number of unique practical situations. This tends to suggest that generalisability, is difficult to assert on the effectiveness of PSMs. In fact, in the approaches taken in this research, several methods have been applied as part of the action research process, each having to be modified to the context of the project, in order for them to be useful.

Rowe and Frewer (2004) state that reflecting on social science approaches to evaluating participative methods can be classified into three types.

- Universal evaluations – ones claiming to produce knowledge that is applicable across all types of participative method and intervention. These require large-scale quantitative studies.
- Local evaluations – comparing between a subgroup of methods or intervention types. These require smaller scale studies that can incorporate more detailed questioning.
- Specific evaluation – used by the majority of researchers, focusing on only one method or intervention. The benefits of this are that the evaluation can be made locally relevant.

Rowe and Frewer (2004) argue that, researchers should aim to achieve as much generality as possible. However, White (2006) argues that preferences for universality or specificity reflect the positivist and interpretivist paradigms respectively. Positivists argue for objective, quantitative, comparative studies capable of revealing the generalisable advantages and disadvantages of different methods, although interpretivist argue that it is more important to evaluate what is achieved by the method in a given context, judged from the perspectives of the stakeholders. Therefore interpretivists are mostly in favour of undertaking specific (single case study) evaluations (Midgley et al. 2013). Eden (1995) argues that the context specific evaluations related to the interpretivist approach offers more insight into the performance and future development of approaches with respect to group decision support systems and advocates that the interpretivist approach to evaluation considers that what really matters is the quality of the original piece of work that provides a platform on which explanation can be built through thick description.

In the context of this research, which is looking at a relatively un-researched area of developing a set of engagement techniques to define sustainability and value in the context of the design of buildings, there are few studies against which the methods developed and applied can be compared. Additionally, feedback on the processes whilst useful in judging the success in a specific context, have limited generalisability.

In terms of the research findings. it is considered that the results of the research in Part 1 cannot be generalised. For example, through Part 1 of this thesis, all the approaches developed and tested were tested on buildings that would be owner occupied. That is would be owned by the stakeholder groups that would also occupy the building, rather designed for a developer with the intention of selling or renting the building after construction. Therefore it could be argued that the stakeholders in the process had more of a vested interest in the project which in the case of a developer who is leading the design and construction of the project for sale upon completion might not. Further testing in different contexts, will help identify which elements of the research will be applicable to a broader range of project contexts. Additionally, projects in Part 1 of the research were all UK based, and international generalisability would require further testing. For example, it would have not been possible within the constraints of the project in Case Study 2A to apply any of the techniques identified in Part 1 of the research due to time and budget limitations as well as the disparate nature of many of the design team. Additionally, as the project was developer led, with uncertainty about who the end users of the building would even be, consultation with future building users would have been extremely challenging.

However, whilst the generalisability of this work is not considered universal, with respect to Rowe and Frewer's (2004) classification, it is considered that for each action research based case study the context, purpose, method and outcomes (as detailed as important in specific evaluations by Midgley et al. (2013)) have all been made explicit. This allows the reader of the research the ability to consider whether the approaches used may be applicable in their context.

With respect to much of the performance data in Part 2 of the research, it is considered that other research looking to inform roof selection, has not considered the generalisability of the information that was being used in the techniques they developed. This research has considered this, looking at the elements of context for different types of information that would be incorporated in the decision support approach. For example, through classification of green roof data by climate type, roof build up, the season of the study along with a summary of the roof build up, provides a means of understanding how appropriate it is to generalise research to another site (see Section 12). Thus it is considered that the transferability of the results to another context is improved. It should be noted that there was limited discussion on the generalisability of individual studies looking at the performance of green roof systems. Further testing of the techniques in different contexts, is a recommendation for further work as part of an iterative approach to developing improved generalisability across a wider range of contexts.

With respect to Part 2 of the research, the generalisability of the development of the process as a whole has not been tested. Utilising the approach to sustainable roof selection developed in a range of contexts and gaining feedback on its usefulness, will give a sense of generalisability of the approach.

16.7 Contributions to knowledge

"Knowledge is information that changes something or somebody - either by becoming grounds for action, or by making an individual (or an institution) capable of different and more effective action" (Drucker, 1990).

This research has integrated numerous techniques in the development of an approach and decision support tool to aid decision makers in making more sustainable roof decisions. This addresses numerous research gaps that were identified through the literature review in Sections 2, 3, and 4.

Many authors have stated the importance of engaging stakeholders in the design process to consider what is considered sustainable and of high value for a project (Kaatz et al., 2005, Kaatz et al., 2006, de Blois and De Coninck, 2008, AlWaer et al., 2008, Alwaer and Clements-Croome, 2010, Austin et al., 2005b, Mills et al., 2006, Mills et al., 2009). However, evidence of approaches to doing this in the building design literature is limited. This research has developed and tested a set of structured techniques for doing this, including a questionnaire, which includes standardised aspects to consider the overarching values of the project stakeholders through utilising Schwartz's Values Survey and questions relating to a project's brief. This further develops the work of Mills et al. (2009) through providing additional questions with respect to project requirements and also through application on a real world project with a follow up workshop to test the technique in the project context. Additionally, the research has developed and tested a range of structured workshop techniques to engage stakeholders in defining sustainability from their perspective.

The contribution to knowledge in Part 1 of this thesis is the development of a set of stakeholder engagement techniques through action research for application on construction projects to determine sustainability themes to inform project decision making.The documentation of the development and testing of this approach addresses Reed and Gordon (2000) call for process professionals and the need to focus on how professionals interact to improve the building delivering process. This also provides evidence of systems thinking and analysis, understanding the process, and robust information as detailed as unchartered areas by Cole (2000). This research provides action research case studies documenting the process of defining the key sustainability and value themes for projects.

The research also contributes to the action research literature, which is not typically undertaken in the construction industry (Azhar et al., 2010). Whilst a few examples exist (Barker et al., 2004, Cushman et al., 2001, Rezgui, 2007), none have considered using action research to test and refine approaches to the definition of sustainability themes for projects or the challenges of decision making with respect to roofs. The success of the techniques developed, despite not having skilled facilitators as noted as important by Reed (2008) demonstrates the success of the action research approach.

The project sustainability themes that emerge from the techniques developed in Part 1 can be used to inform the selection of a set of attributes to assess roof performance. The approach to sustainable roof selection developed, based on a value focused thinking framework, considers how roof objectives relate to project sustainability and value themes. The roof attributes defined through this research, provide a set of ways of measuring the performance of roof options against commonly discussed sustainability themes defined from the literature. The research has defined structured approaches to assess the performance of roofs against some of these attributes, in order to inform sustainable decision making with context specific performance information. The synthesis of such varied approaches to understand what represents high value and sustainable roof systems in the project context is novel.

Acquiring the most relevant information on the performance of different roof systems can be a time consuming and difficult process, as shown through Action Research Case Study 2A. Opportunities to influence sustainability are typically highest early in the design process. Therefore, this research has addressed this issue and provides approaches to access relevant and context specific information, which can help inform the quantitative assessments of roofs. This addresses gaps to the research as outlined by Nelms et al. (2007) with respect to providing an approach to assessing the performance of different roof options. Additionally, the approach developed provides an approach to engage a group of stakeholders in defining project objectives and considering the means through which roofs can achieve project objectives.

A contribution to knowledge made in Part 2 of the thesis is the development of a structured way of acquiring relevant information on the performance of roof systems, using modelling and other referenced calculation techniques, as well as providing a structure to rapidly assess the most relevant journal based research for a particular context.

Macmillan (2006) calls for better information, with improved valuation methods and a new attitude towards evidence based design in relation to the delivery of value in buildings. A recent paper by Russell-Smith et al. (2015) explains how whilst the building industry has developed methods to consider costs, there are still relatively few methods to effectively assess and control a building's life cycle energy and environmental impacts during the design phase. An approach and prototype decision support tool has been developed that includes a set of common sustainability and value related objectives for roof selection. The approach has also been developed with an accompanying tool, which incorporates approaches to identify or calculate the most relevant information regarding the environmental, social and economic performance of numerous roof types. This includes approaches to rapidly accessing the results of building simulation programs. The approach to sustainable roof selection developed, offers both a "bottom up" method of defining the sustainability objectives by project stakeholders and also a "top-down" expert driven approach with respect to performance attributes of roof systems regarding sustainability. Integrating these approaches is argued by Reed et al. (2006) to offer more accurate and relevant results.

In summary, the approach developed integrates softer stakeholder participation techniques with MCDA techniques and approaches for acquiring the most relevant performance data from research, through a value focused thinking approach. Whilst mixing approaches has been done in other fields as demonstrated in the review by Howick and Ackermann (2011), non-have included mixing approaches on building projects, considering how specific system decisions relate to project level objectives. This pragmatic realist approach that mixes multiple methodologies is a new contribution to the field with respect to making sustainable roof selection decisions. This builds upon many aspects outlined as important by authors such as Kaatz et al. (2006) and in doing so provides a technique for considering sustainability decisions early in the design process. It also builds on the work of Grant (2007), Nelms et al. (2007) and McCourt (2007), with respect to developing and incorporating techniques to understand stakeholder values, provide reliable context specific information, approaches for developing and assessing options and improved consideration of risk. Therefore, the development of an approach and prototype decision support tool (DST) for synthesising information to inform roof selection is a contribution to knowledge.

The research has also identified areas of further work, which would be beneficial to investigate and externally validate the tool and techniques proposed in this thesis. These areas of further work are considered in the next section.

16.8 Recommendations for further work

The research has limitations, which have helped identify several areas of further work. These are outlined below.

Consider how the approaches developed could be modified to have a greater emphasis on strong sustainability: Approaches such as the TNS (Robèrt et al., 2002, Robèrt, 2000), advocate starting the approach from a strong sustainability perspective. Such approaches based on strong sustainability principles are now being called for in the construction industry (Mang and Reed, 2011). This has also been undertaken in other contexts such as catchment management (Tippett et al., 2007). However, such approaches have mostly been applied at a larger scale over long time frames. Additionally, many place an emphasis on learning and collaborative design (Reed et al., 2006, Tippett et al., 2007, Tippett, 2005). Others have even explored what shifting paradigms could mean for motivating change in the building industry and social transformation for the built environment through stakeholder engagement.

Review of approaches developed with review techniques developed by others: Further work around this area could seek to consider the processes in parallel to Reed's (2008) eight features of best practice participation. Additionally, future use of the tools could potentially be reviewed through use of the survey defined by Midgley et al. (2013), which would provide a more structure approach to assessing the performance against other problem structuring techniques, based on context, purpose, methods and outputs (although there are several limitations with their approach).

Explicitly consider the themes defined through the analysis engagement techniques in optioneering: Part 1 of the thesis has been concerned with how to elicit the key sustainability objectives and themes on which decision making can be based. However, there has been very little consideration of how decisions can be structured from this information for building systems other than roofs. However, the themes defined through the engagement techniques outlined in this part of the thesis could potentially be used to inform the attributes for a range of project decisions. Therefore, revisiting the themes defined through the engagement techniques at the optioneering stage with respect to a range of project decisions, such as selection of plant, structure, massing of the building, etc. could be beneficial to help stakeholders understand how different design options provide value in relation to the themes they have defined. This would allow stakeholders to explicitly see how the design team have addressed these themes in the process and should communicate how different design options provide value against these themes. This requires further research to understand how this works in practice.

Broaden engagement techniques to include social media: Further work could also look at forms of engagement through less traditional methods. For example, with the rise of social media, techniques for engaging stakeholders in an online environment, where they can leave comments on what they consider to be of value for a project would be extremely useful. Social media platforms could be used to obtain a large amount of information with respect to stakeholders' needs and wants for a project and would allow two way dialogue on issues in a different environment. This may be particularly useful in education environments, such as schools, where a high percentage of the stakeholders are likely be users of such social networks. The researcher has recently undertaken some content analysis of Twitter streams in an attempt to understand design issues, which could be improved in order to provide higher value and more sustainable design options. However, this is in its preliminary stages and much more work is needed in this field.

Form and test an adaptable process of engagement for developing sustainability frameworks: Developing and testing a complete process, from the collecting and analysing of stakeholder opinions, to developing a sustainability and value framework for the project would be beneficial further work. This work did flow from the work presented in Case Study 1B and has also been conducted on recent work by the researcher, but is not considered within the scope of this thesis. This combines the workshop techniques that were outlined in this work, to then define a set of sustainability themes, which were used to develop a framework, which included a set of objectives, along with potential ways in which this could be measured. A follow up questionnaire was then circulated to the attendees of the workshop to test that they considered the themes along with the aims of the themes of the sustainability framework to be representative for the project. This work is currently on-going.

Further consider the integration of regulation: Little consideration has been given to how to integrate regulation in this part of the thesis. This is important, but as discussed briefly in the literature review, the intention of the work was to push beyond purely meeting the minimum legislative requirements and these should always be met unless in exceptional circumstances or where it is considered that they are not appropriate for the project. This should however, not be forgotten in project decision making. This could incorporate in the approach developed a step to screen options that do not meet regulatory requirements as detailed by Nelms et al. (2007).

Consideration of the political and group dynamics of utilising such techniques to understand what is important to the project: Through the values survey and requirements survey utilised in Case Study 1A, there was some resistance to utilising the techniques from an individual in the design team. Further research with respect to the reasons behind this resistance and whether there is general support, apathy or rejection of such techniques would be useful further research.

Alignment and structuring of roof performance indicators through explicitly considering the TNS System Conditions (Holmberg and Robèrt, 2000) and the Planetary Boundaries (Rockstrom et al., 2009a, Rockstrom et al., 2009b): This would consider aspects of strong sustainability in the approach. However, weightings would still be applied by stakeholders on what was considered important in their particular context and this would essentially mean that the tool considers more explicitly aspects of strong sustainability.

Improved visualisation of options: Additionally, improved ways of visualising the options will be beneficial to show the different roof options and potential layouts to clients. This would also benefit from images showing seasonal performance, which could include consideration of aesthetics. For example, in summer months a green roof may have a different appearance as to what it does in the winter months.

Consider whole building performance: Due to the scope of this research and the focus being on roof selection, it does not consider the relationship between roof decisions and other project decisions. For example, analysis is given with respect to technologies that can be located on the roof and their energy generating potential. However this does not balance the energy output and the costs of such systems with other potential competing systems to produce energy from the building that are not located on the roof. This may include a district heating or biomass combined heat and power plant located elsewhere on the project, which may turn out to be a more effective and economical solution. Therefore, methods for accounting for such interactions would be beneficial. This would benefit with integration of the framework developed by Nelms et al. (2007).

Improve the quantity and quality of roof performance information across attributes: Information is still relatively limited for the performance of roof types in some attributes. For example, green roof performance is currently being heavily researched and thus information on the performance for all attributes is still rapidly developing. Results vary significantly, and there is not much work which has been done looking to validate the results of different authors. Additionally, for some aspects such as embodied carbon, the database does not contain regional specific material. Such a database is not yet in existence, and is primarily due to researchers and businesses not willingly sharing their data. The green roof map shown in Figure 12—2, demonstrates locations and climate types where there is currently a lack of green roof research. Additionally, Figure 14—17 shows where there is currently various green roof types. These two images may provide a good starting point for where and in which disciplines to undertake additional research in the performance of green roofs.

Consider utility as well as value: Goodwin and Wright (2009) make explicit the distinction between value and utility. For each course of action described in the tool, the decision maker is required to derive a numerical score to measure its attractiveness. In doing so, this is considering the *value* of the course of action. Value of a course of action is defined to be a singular number, which represents no element of risk and uncertainty. The utility of a course of action is referred to as the score of a course of action, which involves risk and uncertainty. Therefore, rather than putting in a singular number to represent performance, the user is asked to put in the performance in relation to a probability distribution. As the performance of green roofs is not able to be modelled particularly accurately at present, consideration of utility, is likely to offer improved consideration of decision risk. Therefore, consideration of utility is proposed as a further area of research.

Consider the impact of surrounding buildings: The modelling and selection methods presented do not account for the impact of surrounding buildings. Therefore, this element of a project's context is not accounted for. In some locations this may be significant. Methods of inserting surrounding buildings into the generic models would be beneficial to understand the impact of factors such as shade.

Consider layout as well as areas: This is related to the above point on the impact of surrounding buildings. The current DST assumes that the roof is exposed and flat, with no over shading, and also that the locations of various combinations of roof types are insignificant. However, further work would benefit from defining approaches to informing the optimum layout of various systems to achieve decision objectives. For example, location of solar PV in areas of highest solar radiation; green roofs in accessible areas etc.

Consider the integration between water proofing and surface covering and optional technologies options: The 'technology options' applied to roofs do not impact on the performance of the underlying water proof covering. This does not truly represent how the roofs will perform. For example, installing solar photovoltaics above green roofs will provide shading to the green roof and therefore different conditions to an exposed state. This will impact on performance, for example their water consumption and surface temperatures. Additionally, if the solar photovoltaics are cooler, due to being on a cooler roof, then their performance is likely to be better as they perform best when cool. Further work would be to understand the impact of the interaction between different roof systems when on top of one another. Scherba et al. (2011) have looked at the impact of the shading of Solar Panels on the urban heat Island effect in more depth than done in this study. Whilst the researcher could match the results shown in their paper on some roof types, it was not possible on others. Therefore, the methods that they outlined for doing this have not been considered. However, such aspects present a real opportunity for further work.

Improve the process of defining values for performance: The conversion of the performance of each option to a normalised score is done on a linear basis, scoring the best performing option as 100% and the worst performing option at 0%. This assumes that each increase in performance carries a directly proportional increase in value. This may not be the case in reality. For example, increases in performance towards the highest performing end of the scale might not be equivalent to equal increases in performance towards the lower performing end of the scale for a particular attribute. This is considered appropriate by Edwards and Barron (1994) if the improvements at either end of the scale are not considered more than twice as important as at the other end of the scale.

However, if improvements at one end of the scale are considered twice as important as at the other end of the scale, further work would be beneficial to allow the user to input specific value curves to represent the added value that improvements in the values of the attribute correspond to in reality. This would allow the user to consider for example how increasing the performance of an option from 0 to 1 is twice as important as improvements in values from 1 to 2. Such a user specified value curve could be input to convert between the raw data and the dimensionless score on each attribute. Whilst this is likely to be a time consuming process, it would improve accuracy and may be important for high value decisions.

Additionally, the current approach assumes that highest or lowest value is either best or worst. For example in the case of solar thermal energy production, it is considered that more energy produced is always better. However, in some situations if the amount of energy produced is more than the building uses, this could become problematic. Therefore, allowing the user to define specific value distributions would be beneficial.

Consider un-referenced / user input performance measures: Although not part of the prototype version of the tool, over time it is expected that hovering over the cells of the table, the tool will provide guidance on how context specific the data is and any assumptions that have been used, thus providing the decision maker or the design team with additional information if they desire to see this. For example, at the moment all embodied carbon data comes from the Green Guide (Anderson et al., 2009)), which follows a methodology that is most suitable for the European Market, and thus when using in an international context, this should ideally be highlighted to the decision maker explicitly.

Improve integration with techniques to consider performance: There is the possibility for further integration of the outputs and roof generation options and the decision making process. For example, smarter integration within building modelling packages such as Energy Plus could, potentially start to optimise roof options in line with decision attributes outlined at the start of the decisions making process, depending on the variables input and the performance ranges weighted as being important. Whilst computational power at the moment would limit the speed at which results would be available for significant numbers of roofs, this over time would be reduced to be significantly quicker so that it could potentially be run live in a workshop environment. This would also reduce the need to keep a database of the performance runs of different roof types for different climates, which due to the number of data points and variables considered can be significant and large.

Development and adoption of a standardised coding systems for reporting on green roof research: It would be useful if the roof selection tool could automatically include the results published by authors on the performance of roofs on different attributes. For example if research was published in a standardised way for the runoff retention and thermal performance of different green roof options, this would greatly improve the data available and allow meta-analysis of data to inform decision making.

Improve the coding of Roof DST and user interface: Currently the DST is in spread sheet form, with many tabs, and references to many databases. Additionally, some elements are manual and require taking information from one output and placing it in the input to another calculation or process. This is time consuming and also means that there is increased opportunity for human error.

Develop a filter for roofs which do not meet essential requirements: Additionally, the roof space is sometimes in high demand for a number of uses, this is shown through the case study of roof selection for a Middle Eastern masterplan (Section 11). For example, area required for mechanical plant, may be competing with the area required for photovoltaics to meet energy reduction targets, or accessible amenity space at high level. Additionally, some aspects of roof selection may have to be fixed and therefore the decisions on what roof systems to select may be limited to a smaller area of the roof. For example, if mechanical plant for the building cannot be located anywhere but the roof, then this is a necessary objective. Whilst some elements of this can be incorporated through the DST, for example plant area could be set as an attribute, and plant space set as a roof system, there is no way of currently defining necessity other than to manually remove all options that do not meet the requirements. Ruling out unsuitable roof systems (or combinations of systems) prior to analysis, for example, those that do not meet certain mandatory criteria would be beneficial and simplify the process. The current tool does not do this and it is considered a worthwhile addition to the functionality of the prototype tool. This would involve setting minimum performance requirements for certain attributes and filtering out options that do not meet this performance.

Test the synthesis between Part 1 and Part 2: Further work to understand the efficacy of utilising Parts 1 and 2 together to inform sustainable roof selection would be beneficial as this has not been tested in the project environment. This requires a project with a client willing to do so and for a team to be involved from project inception to at least RIBA Stage D of the project, and ideally beyond, to assess how decision making is informed from concept to completion. Such a long term longitudinal study would benefit from participant observation at the workshops, collection of feedback on the efficacy of the approach, potentially with an in depth consideration of how best practice factors, outlined by Reed (2008) as important with respect to stakeholders participation, can be integrated within the process.

Engaging stakeholders in the weighting of roof performance: Engaging stakeholders in the weighting procedure for roof selection requires further investigation. It is likely that the stakeholder group involved in this process will be a more focused group of stakeholders, rather than the wide range of project stakeholders intended to be engaged in defining broader project requirements. They will also require some understanding of the attributes used for roof selection in order to be able to assess and quantify the importance of the swing between the best and worst performing roof option. Such work could build on the research, such as that by Hajkowicz (2008), who consider how multi-criteria analysis techniques can be used in supporting multi-stakeholder environmental decisions. This could support the further research recommended by Hajkowicz (2008) around how decision makers interact with MCA models and how decision procedures can be informed by a structured, rational and analytic approach, and where decision procedure analysis stops and judgement begins. This could also benefit from building on the work undertaken by Fan et al. (2010) on Group Decision Support Systems with respect to value management in the construction industry and the critical success factors that they identified. This could consider how the decision approach can be used to improve group decisions in relation to the environmental setting (i.e. workshops for weighting or computer based weighting), the workshop duration and number of participants, the capabilities of the group decision support system/approach which include the ease of use, reliability, responsiveness and utility.

All parts of the work would benefit from the application and documentation of the approach, tool and techniques developed and applied through this research, to test their generalisability to different contexts. Some of the tools and techniques outlined in this work are already being used in the project environment and the researcher is undertaking further work to communicate and apply the research undertaken in this thesis in the industrial context.

16.9 Conclusion

This thesis has drawn on ideas from practice and a wide range of disciplines to develop an approach to sustainable roof selection.

The research began with a review of several strands of literature to identify research gaps and consider where research from other fields could be of value in addressing such gaps. The gaps identified included a lack of stakeholder participation in the development of sustainability objectives for building projects. There was a growing consensus that approaches to inform decision making with respect to sustainable design were required early in the design process.

This research therefore considered the wider literature, and approaches that have been used to structure complex problems with stakeholders and aid in multi-objective decisions. Techniques for considering what stakeholders valued and considered important from a sustainability perspective were developed based on this literature and refined through action research within the sponsoring organisation and on client facing action research case studies. These techniques were considered useful by the stakeholders surveyed in capturing their sustainability and value perspectives.

The second part of the research focused on the challenges of roof selection and how these could be better addressed. This started, by considering the difficulties of informing sustainable roof selection in a different context to previous research. This highlighted key issues with respect to a lack of structured information on which to base roof selection. Approaches were therefore developed to address this research gap. An approach was then developed for bringing together the performance of roofs systems with project sustainability objectives. This is considered a pragmatic realist approach combining soft objectives defined through consultation with stakeholders with the technical performance of roof choices. In summary the approaches developed through this work synthesise a range of previously disparate information and data sources into one approach, which endeavours to incorporate stakeholder values into the design of building projects.

The research concludes with a reflection and evaluation on the research process. Limitations and areas of further work are then identified.

The approaches developed through this research will continue to be applied on projects and refined through the process, thus more iterations of the action research loop will be conducted. Additionally, the researcher will continue to develop the areas of further work identified through the research as a practitioner in the sponsoring organisation.

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THE DEVELOPMENT OF AN APPROACH AND DECISION SUPPORT TOOL TO INFORM SUSTAINABLE ROOF SELECTION

Volume 2 of 2 (Appendicies)

Philip Roy Hampshire

A Thesis Submitted for the Degree of Doctor of Engineering

University of Bath

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Appendix A Decision making with no data: The challenges of technology selection in the building industry

Decision Making With No Data: The challenges of technology selection in the building industry

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Abstract

The building industry is increasingly requiring rapid assessment of new technologies and systems. An emerging category of sustainability engineers and consultants are being asked to determine sustainable choices for the built environment, for a range of situations, from individual buildings up to masterplans for new cities. The timeframe to define and assess potential options is a matter of days or weeks, before reporting back to a client with a range of options, and typically a recommended course of action. This raises many problems, primarily how to assess new 'sustainable' technologies and systems. These challenges are identified, and through a case study example, resolutions are proposed and discussed before conclusions are made regarding decision making in this area.

Keywords: decision making, sustainability consulting, assessment systems

Introduction

In recent decades the drive for more robust decision making has lead to an increasing amount of information being generated about sustainable design options, and the development of advanced simulation techniques. This has undoubtedly had a positive effect on the building industry, allowing detailed designs to be refined and optimised. Over a decade ago Cole (2000) stated "The research community has offered considerable knowledge on green buildings over the past couple of decades." However, he goes on to comment that, "there are five areas which remain relatively uncharted (1) good robust information, (2) [going beyond] technological issues, (3) systems thinking and analysis, (4) understanding the process (5) good communication." The authors of this paper believe this is still the case today.

This paper considers these areas, describing the role of the consultant, the context within which they work and the challenges they face when assessing sustainable design options. A short case study is then presented looking at how these challenges can be addressed early in the design process.

Context and Challenges

1. The Consultants World

In an idealised world, the design consultant would be presented with clear criteria upon which to base system choices; have complete information regarding the performance of all the options over their lifecycle; have enough time to be able to scrutinise this information and make well grounded recommendations with minimal amount of uncertainty and risk. Unfortunately, the design consultant's environment is typically pressured, with little time, project fee or information on which to base decisions. Additionally, decisions with respect to sustainability often require integration with other building systems which if not decided upon and designed in from the early project stages, will be too costly to incorporate at a later date. Therefore decisions need to be made and justified quickly under a high degree of change and uncertainty. This is often done in highly different contexts between projects (climate, brief, stakeholders etc.), meaning generalising and using information acquired from past projects is difficult.

2. The Role of the Sustainability Engineer/ Consultant

The role of the consultant is typically to support and inform, but not make decisions. This can be challenging as the situation and problems that they are aiming to help resolve are typically messy and unstructured. These problems are characterised by the existence of multiple actors with multiple perspectives, incommensurable and/or conflicting interests, important intangibles and key uncertainties, (Mingers and Rosenhead 2004). To resolve these issues, consultants also have to relate the performance of different systems back to criteria that the client considers important, and at an appropriate level of abstraction.

3. Building Simulation Programs

The performance of various systems and their interaction with the building can be modelled through building simulation programs. This is important when refining and optimising designs. However, conducting simulations at an early project stage on a number of design options is not typically feasible due to the time restraints and the required data inputs being uncertain and in flux. Further issues arise with respect to what aspects can be modelled and what is important in the selection of options. Many of the available tools and techniques tend towards quantitative, rational, 'hard' scientific approaches – for example computer simulated models which try to capture the complexity of the multi-modal interactions inherent in our ever changing world. These struggle to incorporate the softer, value led elements of sustainability Therefore, one has to question whether such techniques are suitable for informing decisions early in the design process when consideration of options from a sustainability perspective is required.

4. Proving the Value of Sustainable Choices

As discussed, conducting detailed simulations is not typically feasible in the early design stages, when decisions around the inclusion of 'sustainable technologies' are required. Therefore it is difficult to quantify the technical performance of proposals. As this information is used to indicate operational efficiencies which can in turn be translated into economic benefits, a focus on capital costs tends to negatively dominate decision making.

To counteract this, and in a bid to prove their value, past precedents and simplifications are typically used as a proxy to indicate potential payback times, a reduction in carbon emissions and energy or water savings. However, the data is uncertain, the payback of many sustainable design options is often long, and if performance in these areas is not considered of value by the client, this information is unlikely to justify the inclusion of more sustainable technologies, unless enforced through regulations or policy. This can leave designers frustrated as designs considered to improve environmental and social sustainability are often discounted as they are considered by the client to not offer value. Paradoxically, this makes such options unsustainable as they have not sustained their existence past the design stage.

Whilst, value has traditionally being judged in terms of location, quality, function and aesthetics (Barlet and Howard 2000), value can be represented in many ways depending on the client or stakeholder. Therefore it is important to get a holistic picture of what a client/stakeholder group values for the project, and justify design options in these terms, not just aspects which are easily quantifiable such as energy, carbon and water use. This is something that is not possible through solely quantitative techniques. This requires close collaboration with the client, alongside analysis and prioritisation of their requirements.

5. Environmental Assessment Methods

Building Environmental Assessment Methods (EAMs), such as Leadership in Energy and Environmental Design (LEED) have grown in popularity over the past decade. EAMs consist of a number of criteria on which to assess the environmental performance of buildings. These criteria have been defined and then weighted in terms of importance by a group of experts and industry professionals, often for a particular building type and climate. They have received much attention across the industry as they offer a scoring system on which to judge the environmental performance of buildings.

Consultants then score the performance of buildings and technologies across a range of criteria in ways defined by the framework. These scores are then weighted and summed to give an overall rating or accreditation. This score is then often used as a way of marketing the environmental performance of the building. They are also seen as desirable by designers and clients who tend to like the quantitative and prescriptive nature, and the ability to brand their building as ‘environmentally sustainable’. EAMs have undoubtedly had a positive impact, as they have brought environmental issues to the forefront of design. They also offer a framework which can be used to inform design. However, recently EAMs have started to be used outside their original scope in new contexts and removed from their countries of origin. In such situations when EAMs become drivers of design they can have a significant negative impact. For example, utilising LEED (developed for the USA) in the Middle East, can reward design options that are not environmentally beneficial in that context. Additionally EAMs do not address wider sustainability considerations such as social or economic aspects.

Methodology

The situations in which sustainability consultants and engineers have to make decisions exhibit the characteristics of hard decisions (Mingers and Rosenhead 2004). Such problems can rarely be addressed from just one type of research method. Therefore the research has used a multi-method approach, utilising a plurality of methods, both qualitative and quantitative, within real-world interventions (Mingers and Brocklesby, 1997). The following case study represents how different approaches can be used to help inform decision making on a project. For each section of the case study a brief description on what was carried out to address some of the above issues is given, followed by reflection on the process used.

Case study

The case study project is a multi-building, mixed use, urban development located in the Middle East in a sub-tropical arid climate. The project has been anonymised but is considered by the authors as typical of such type of development. At the concept stage the project had numerous architects, consultants and engineers working in different offices around the world progressing the design. The client was represented by a company based in the Middle East. The case study focuses on consideration of the roof options for the buildings from a sustainability and value perspective. It aims to address some of the challenges previously outlined through a simple four stage approach which involves; (1) Identification of requirements; (2) Prioritisation; (3) Comparison; and (4) Presentation of Information.

1. Identification of Requirements

The relevant roof related requirements were initially identified and captured for the development (see Figure 1). This was considered necessary as the project requirements spanned several documents and consisted of hundreds of pages. In this form it was hard to see and work with the requirements for decisions relating to specific technologies and roof systems. Condensing this into a manageable form on which decisions could be framed was important and it meant that requirements that may have been in conflict with sustainability considerations, such as of energy, water, waste etc could be assessed in line with wider project drivers.

Reflection on the process

Keeney (1992) argues that 'the standard way of thinking about decisions is backwards: people focus on first identifying alternatives rather than on articulating values'. In contrast, one may argue that a project's requirements make the project and client's values explicit.

However, it is rare for project requirements to be prioritised in order of importance, and for them to be specific, measurable, achievable, realistic and timebound (SMART). Therefore further effort is required to transform them into a complete set of operational, preference independent and non-redundant objectives on which to base decision making (Keeney and Raiffa, 1976).

Going through such a process, whilst initially time consuming, offered a way of translating what can often be messy and unstructured early in the design process into a tangible set of criteria against which to make a decision. Showing this explicitly for each technology selection allowed the decision maker to understand what the consultant had defined as important to consider in the analysis. It also allowed the consultant to consider these as objectives on which to judge the options. Additionally this allowed the importance of decisions related to different system choices to be highlighted. If the decision relating to a particular system or design, is likely to influence lots of requirements and objectives then it merits more attention than otherwise.

2. Prioritisation

On the case study project it was unclear what the design team should focus on in the early design stages. This is not uncommon in projects. Through consultation with the client and architect it was eventually established that LEED was a priority. Other requirements that were also of high importance included a desire to generate a significant percentage of the project's energy from renewable technologies. These two aspects are complementary in many respects meaning that achieving one helps the achievement of the other. However, where requirements are not complementary and tradeoffs are required prioritisation is important. This allows the design team to

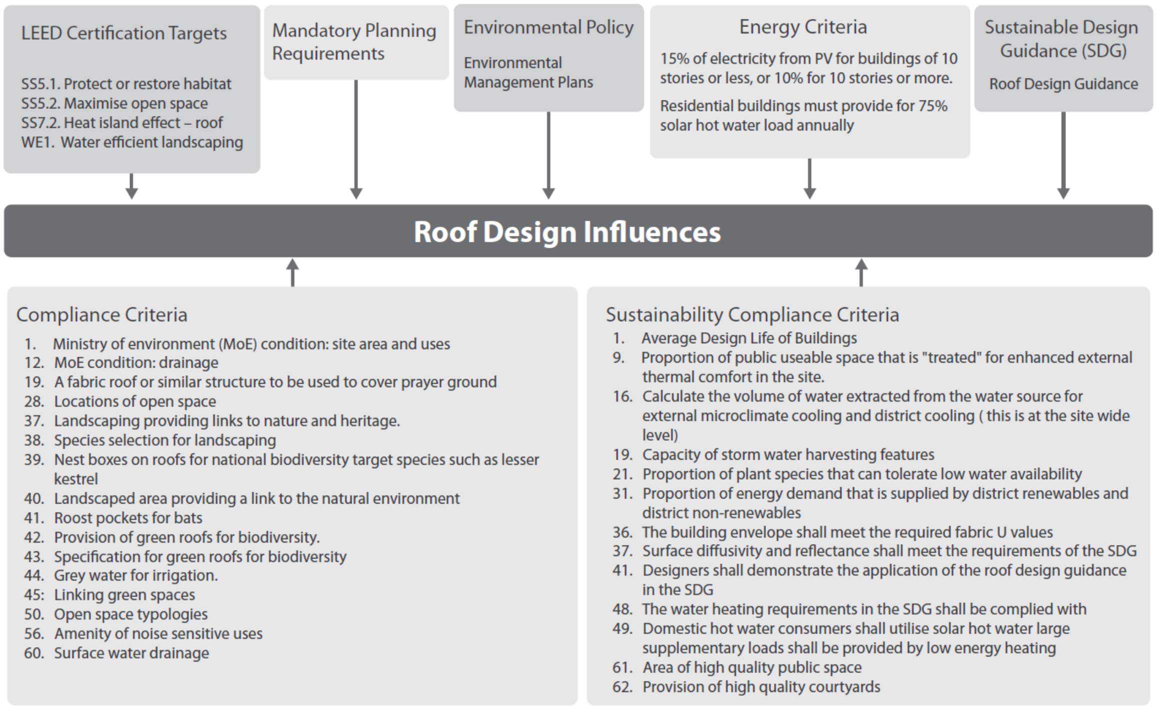

Figure 1: A selection of roof related requirements and drivers

progress the design knowing which objectives are most important to achieve when it is not possible to 'have it all' given the project constraints. These constraints may include the budget, the site and in this example case the roof area. The requirements for LEED credits and renewable energy generation had to be considered in parallel with other project requirements which included utilising roof spaces as high quality communal areas to include pools and garden space. The roof area consisted of approximately 30,000m^2 of the 45,000m^2 plan area of the development. Therefore, in order to achieve many of the landscaping requirements along with the desire to have open air pools and gardens the roofs space had a lot of competing interests.

Requirements were never explicitly prioritised so the design team had to make assumptions on which ones were considered most important.

Reflection on the process

Prioritisation of what is most important to achieve is rarely done on projects. Clients' aspirations change over project lifetimes. Initially there is a tendency to 'want it all', but as budgets and time become pressured, holistic sustainability often becomes reduced to a handful of key features. But without understanding priorities, the designer is not informed as to what is important to progress through the design. Therefore requirements/targets should be prioritised in order of importance. This is highly important when considering sustainability and options which will inevitability involve trade-offs.

The process of prioritisation should be done ideally in collaboration with the client, but where this is not possible due to the structure of the project team, the design team should make their assumptions explicit on what they have prioritised. Additionally it should be considered that access to the client can be difficult as the client is typically 'multi-headed' and represented by a team of people. This team may be in another country and primary access may be through an architect. Feedback can take days or even weeks as discussions go through a chain of people. When decisions need to be made in a short time period to allow the design to progress, consultation with the client can be impractical.

Whilst LEED was a driver for commercial and marketing purposes, LEED was designed in the USA, primarily for use in the USA. Hence, design features may achieve LEED points even when they did not represent a good/sustainable design for the Middle East. This was made explicit to the client when it was the case.

Additionally, whilst requirements should be prioritised at this stage they also need to be assessed as to whether they are realistic. This was quickly done using assumptions and calculations based on rules of thumb.

3. Comparison

When considering roof technologies on the case study project a simple matrix was formed that allowed the design options to be compared in relation to the requirements (see Table 1). The performance of various systems could then be explicitly compared against them. This was done through expert understanding on qualitative issues alongside high level assumptions to inform simple rule of thumb models for aspects more easily quantified. Showing high level performance of numerous options in relation to the project requirements on one page was beneficial for the following reasons:

- It showed how the different options were likely to perform against a wide range of criteria on a simple scale, without the requirement to understand the different metrics required to quantify the performance.
- It showed the tradeoffs that were inherent in any technology selection. For example solar PV and solar thermal performed well in terms of energy related requirements, however they performed poorly when considering requirements relating to biodiversity (habitats), open space and urban heat island impact.
- Additionally it showed where potential synergies may be achievable through combining different technologies and systems. For example combining solar PV or solar thermal with roof gardens may enable many requirements to be achieved simultaneously.

Reflections on the process

When making decisions regarding design options, sustainable options can be easily compromised if they don't perform 'the best' on any of the individual decision criteria. This means that they are easily ruled out when considering any of the criteria in isolation. Sustainable technologies or design solutions often perform a multitude of services, although they may not be the best provider of any single service. For example green roofs, do not perform the best in terms of mitigating the urban heat island effect, reducing heat transfer into rooms below, or reducing runoff. Each of these things individually can be done better by other systems or technologies; reducing heat transfer can be done more cheaply by insulation; reducing runoff can be better quantified and captured through rainwater harvesting; and urban heat island better mitigated through highly reflective surfaces. However, none of these other systems in isolation can do the multitude of things that a green roof can. Additionally, these options do not offer the other benefits of green roofs that may be considered of value. For example, the green roof could offer external garden space with good views, increase biodiversity, improve acoustics and aesthetics of an otherwise bland space. These are issues that are much harder to quantify/model, but may be considered of much more importance to the client. By holistically considering options through the decision making it might be that the Client can see the value of certain sustainable design options. In these circumstances the sustainable option has a much greater chance of making it onto the project.

This is not an uncommon problem with respect to decisions involving multiple objectives. Such decisions often involve lots of information that requires handling simultaneously. Without a system to support the decision, the decision maker is forced to use simple mental strategies, or heuristics in order to make a choice unless there is a system in place to support their decision. For example, unaided decision makers often have difficulty in making tradeoffs between objectives. As a result they tend to use non-compensatory strategies so that the relatively poor performance of an option on one objective is not compensated by its good performance on other objectives (Goodwin and Wright, 2009). Simple comparison systems can help in such situations.

Whilst it is accepted that weighting and normalising the scores can be beneficial this was not done on the case study project. The reason was that this would have required a significantly greater investment of time in the initial project stages, and the authors believe that it would not have brought a much deeper insight to allow decisions to be better informed. Techniques such as multi-criteria decision analysis (MCDA) which attempt to weight and score options on a scale can play an important role in decision making. However, it was considered that such an approach would allow the decision maker to simply pick the best scoring option without considering the potential synergies of combining options, and the potential tradeoffs that would inevitably have to be made. Decision making should allow mutual learning to take place and put the decision maker in a more informed position, rather than simply giving a number which represents what the consultant considers to be the best option based on the consultants own weightings and scores (Keeney, 1982, Goodwin and Wright, 2009).

At this early stage, simple rule of thumb modeling was done to assess performance of easily quantified aspects such as energy from Solar PV. With respect to softer objectives, scores had to be based upon the consultant's own understanding and knowledge. Such scoring can be prone to biases. This raises questions with how to militate against these biases? Whilst on the project, the scoring was reviewed by another consultant to assess that that it seemed feasible, future work will look at getting a number of informed experts to score the options based on their knowledge in order to understand the variation and level of disagreement. Group pressures can be avoided by eliciting these judgments anonymously and independently (Surowiecki, 2005) and future work could usefully explore the role of techniques such as the Delphi method which can be useful in guiding these judgments to a consensus (Rowe and Wright, 1999).

4. Presentation of the information

In the project context the consultant's role is often to inform the decision making, but not actually make the decision. This means presenting the client with clear information on which they can make their own decision. From a consultants perspective it is important to inform the design through showing what different options may involve to the different disciplines. For example what does the architect need to consider when progressing the design? This was done on the case study project through detailing the areas of different technologies required for the roofs to meet a range of requirements and maximise the value of the roof space (see Figure 2). This then allowed the architect the freedom to be able to use their skills to do this in an aesthetically pleasing way and integrate with other building systems.

Reflections on the process

This simple and visual approach was received well by the Client and the wider design team as it informed what combining different systems would mean in terms of the design in this context. It also became a something around which dialogue could be based. Also in the case of many disciplines, it was not necessarily important for them to understand the technical performance of different roof systems, but only how it impacted on their area of work i.e. the areas that needed to be incorporated and where the technologies should be placed to perform optimally. This simplification was therefore advantageous and proved to be at an appropriate level of abstraction to communicate to a wide range of stakeholders. Further information was supplied regarding what the build-up of each roof type meant to different disciplines

Conclusions and Further Work

The work presented in this paper represents a sustainability consultants attempt to support decision making on a complex project, with a high degree of uncertainty and under significant time constraints. It is considered that whilst the work contained some simplifications of more academic methods, the decision making frameworks presented were useful under the circumstances. Many of the pressures are generic across projects, like a desire to make decisions quickly under uncertainty. Limitations of the approaches presented included the difficulties in prioritising the importance of different criteria and further work is currently been conducted around these areas.

Additionally, with a qualitative scoring method, there is likely to be bias in the scoring. Further work will look at ways in which this can be assessed and accounted for.

Table 1. Comparison of options against requirements

Key: ✗ no contribution ✓ some contribution ✓✓ good contribution ✓✓✓ best contribution

	Requirement	**Desert roofs**	**Roof Gardens**	**High Albedo "Cool" Roofs**	**Solar PV**	**Solar Hotwater**
LEED	SS5.1 Protect or restore habitat (1 point)	✓✓✓	✓✓✓	✗	✗	✗
	SS5.2 Maximise open space (1 point)	✓✓✓	✓✓✓	✗	✗	✗
	SS6.1 Stormwater design - quantity control (1 point)	✓✓✓	✓✓✓	✗	✗	✗
	SS6.2 Stormwater design - quality control (1 point)	✓✓✓	✓✓✓	✗	✗	✗
	SS7.2 Heat island effect - roof (1 point)	✓✓✓	✓✓✓	✓✓	✗	✗
	WE1 Water efficient landscaping (1 point)	✓✓✓	✓✓✓	✗	✗	✗
	EA2 On-site renewable energy (4 points)	✗	✗	✗	✓✓✓	✓✓✓
Compliance Criteria	Drainage - storm water runoff generated within the project to be collected through a positive drainage system and discharged to the public sewer network	✓	✓✓✓	✗	✗	✗
	A fabric roof or similar structure to be used to cover prayer ground…	N/A	N/A	✓✓	✓	N/A
	Location of open space	✓	✓✓✓	✗	✗	✗
	Landscaping – providing links to nature and heritage	✓	✓✓	✗	✗	✗
	Species selection for landscaping: Landscaping – providing links to nature and heritage	✓✓✓	✓✓✓	✗	✗	✗
	Nest boxes on roofs for national biodiversity target species, such as lesser kestrel	✓	✗	✗	✗	✗
	Landscaped area providing a link to the natural environment	✓	✓	✗	✗	✗
	Roost pockets for bats	?	?	✗	✗	✗
	Provision of green **roofs** for biodiversity	✓	✓	✗	✗	✗
	Specification of green **roofs** for biodiversity	✓	✓	✗	✗	✗
	Grey water for irrigation	✓	✓	✗	✓	✗
	Linking green spaces	✓	✓	✗	✗	✗
	Surface water drainage	✓	✓	✗	✗	✗

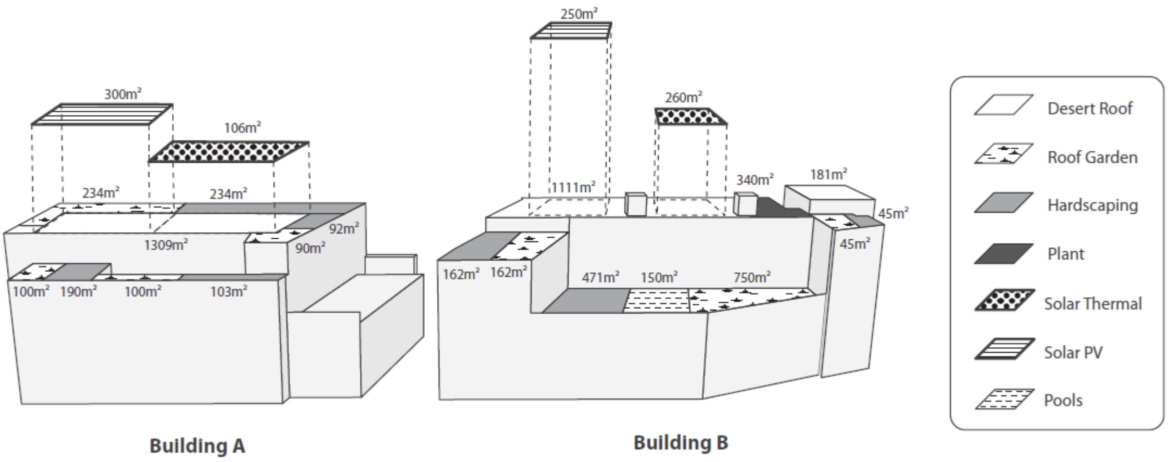

Fig. 2: Schematics showing roofscape area recommendations for design development.

World Congress on Water, Climate and Energy

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Disclosures

The authors have nothing to disclose.

Appendix B Improving the understanding of what represents project value to inform project decision making

Improve the understanding of what represents project value to inform project decision making

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Motivation & Context

"Value Delivery is the goal of all projects" (Austin, Thomson et al. 2005). However, what represents value? Many would argue that this is a design that best meets the requirements of the project. However, often priorities are not made clear, additionally the requirement documentation may be unrealistic, or not represent the thoughts of the wider project stakeholders. These are issues that often leave designers asking, *'where should they focus their efforts to give true best value?'*

Therefore this research seeks to quantify what represents value for a project and its stakeholders through a applying a combination of techniques developed from academia. It is intended that the defined approach can be then used to give a well grounded set of criteria on which to base decisions with respect to sustainable design options. Through such approaches the value of sustainable design options can be considered through what represents value from a holistic perspective. Some of the results from a trial application of the approach developed on a case study project are presented.

Methodology

The situations in which sustainability consultants and engineers have to make decisions with respect to value and sustainability exhibit the characteristics of hard decisions (Mingers and Rosenhead 2004). Such problems can rarely be addressed from just one type of research method. Therefore the research has used a multi-method approach, utilising a plurality of methods, both qualitative and quantitative, within real-world interventions (Mingers and Brocklesby, 1997).

This approach developed builds upon techniques highlighted from a comprehensive and cross disciplinary review of the literature, and further developed through consultation with industry professionals from within the sponsoring organization and its sister company Happold Consulting.

The first stage of the approach involves circulating a questionnaire to understand the stakeholders' opinions on what represents value to them. The questionnaire includes a generic aspect which seeks to understand peoples' fundamental values. This is based on the Schwartz Values Survey (Schwartz, S. H. and P. Z. Mark, 1992) adapted for the use in construction by (Mills, G., S. Austin, et al. 2009) to understand the fundamental values of the stakeholders of the project. The project also includes a project specific aspect which seeks to understand which requirements from the project brief are priorities to achieve. It offers the advantage that stakeholders can give their opinions anonymously, without politics or power structures coming in to play. The results of the questionnaire are then analysed to gain a deeper understanding of what represents value for the project. Diversity can be shown through plotting individuals' thoughts and the collective thoughts of different stakeholder groups on a radar graph to show variances and alignment in priorities. At this stage of the process, the designer should also analyze the project requirements and look for potential conflicts and possible win-win opportunities. The relationships between the requirements and the stakeholders can also be tied back to the generic values of the values survey. The relationships can be well represented using systems dynamic diagrams, with green arrows representing positive 'win-win' relationships and red arrows representing 'potential conflicts'.

However, it is important to understand that whilst this can be useful to identify agreement and disagreement amongst stakeholders and show relationship requirements, it does not provide the deeper understanding and learning which is required to inform decision making in the project context. Therefore the results and analysis from the first stage of the process are then taken to a workshop and provide 'boundary objects' around which value can be discussed (Whyte, J. and S. Lobo, 2010). Boundary objects explicitly state a set of results openly and allow a common understanding to be developed. They also allow opinions and knowledge to be openly stated without people having to state their own thoughts and position which can reduce conflict. This aspect is also considered important to gain a mutual understanding of what represents value and also collectively learn of potential conflicts between stakeholder groups. During the workshop, time is also set aside to discuss the results and points of interest identified through the analysis.

The technique of speed storming (Joyce et. al 2010) is then used to ask what is currently wrong with the current building and how the new design should improve upon this in their opinion. The advantages of speed storming in comparison to 'brainstorming' are that everyone can be involved in the process as people discuss their thoughts in pairs. It also helps militate against groupthink and allows a variety of opinions to be expressed on post-it notes. The point of this is to explore what is important from a different angle, in order to understand the project's priorities.

Results from case study application

Figures 1, 2 and 3 show some of the resulting output and analysis from the initial stage of the process the approach outlined above. With respect to the survey distributed amongst stakeholder groups, responses were achieved from 4 of the management team, 4 teachers, 9 governors and 4 design team members. This shows a much wider perspective than is typically achieved in a design situation. Figure 1 shows the individual stakeholder values and how through simple averages, a project culture can be defined. Standard deviations were also conducted to show the disagreement amongst stakeholders. The project brief had a strong sustainability theme however, figure 1 show the stakeholder values related to protecting the environment and unity with nature were not high scoring values. This provided a discussion point in the workshop.

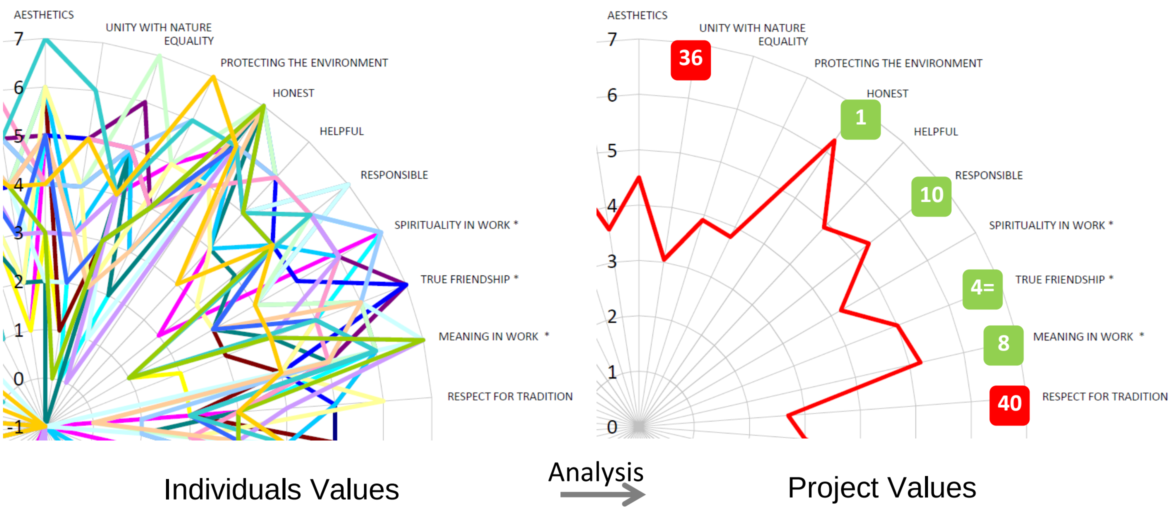

Figure 1: From Individual Values to Project Values through analysis.

Figure 2 shows that the design team was not necessarily focusing on requirements considered of value to the stakeholders. It also provides a potential way of ranking the requirements on a project and thus demonstrating where the design team should focus more effort. Simple systems dynamics diagrams then show relationships between requirements and how sustainability considerations align to provide potential ‘win-wins’ across requirements and ‘possible conflicts’ between requirements and sustainability related issues. This then allows the client to think about sustainability in relation to what is important to them and also relate these to their stakeholders’ values made explicit through values survey and ranked requirements.

REQUIREMENT	RANK			
	MANAGEMENT	TEACHING	GOVERNOR	DESIGN TEAM
01 Offer more space (larger classrooms)	15	3	5	13
02 Offer dedicated specialist rooms (ICT suite, artroom, library, shower room, food tech).	8	14	14	15
03 Be energy efficient and be environmentally designed	7	8	3	7
04 Be attractive and airy offering views for all	8	8	6	6
05 Have direct access to outdoors from all classrooms	13	15	16	1
06 Be a practical and pragmatic building with flexibility for future changes, development and potential expansion	2	5	1	11
07 Have creative flair and memorable design	8	8	8	7
08 Have a garden area for pupils to grow plants/vegetables	4	5	17	1
09 Have a modern IT network and www. connectivity	11	12	15	15
10 Be easy and cost effective to maintain	4	8	4	1
11 Incorporate state-of-the-art building technologies	16	18	8	17
12 Use and demonstrate sustainable use of materials	13	17	6	13
13 Be in keeping with its setting	1	12	8	1
14 Make the most of natural resources (sun/shade, orientation, wind and views)	2	5	2	1

Figure 2: Excerpt from Requirements Ranking Table. A score of 1 represents the most important ranks.

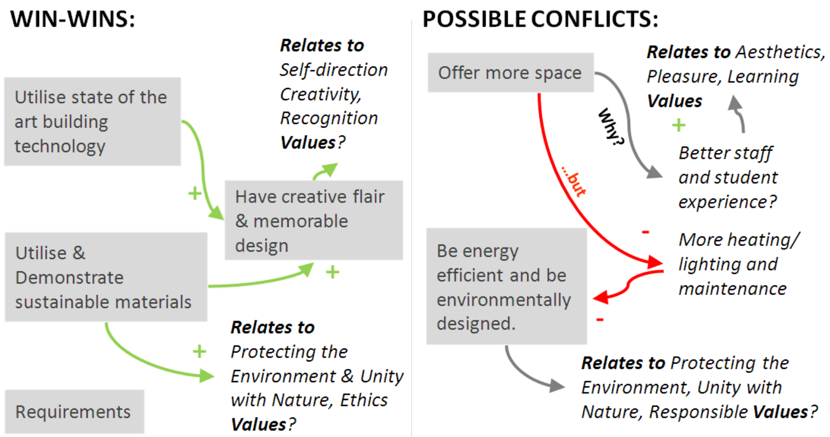

Figure 3. A systems dynamics approach to simply show the relationships between requirements

Conclusions & Industry Relevance

A framework has been developed to gain a greater understanding of what is considered of value to the project stakeholders and make priorities explicit for the design team to see. This was developed from academic techniques from a variety of disciplines and has been refined through internal testing within the sponsoring organization and also testing in the design stages of a case study project. External feedback from the client was positive and they stated that they would be keen to undertake the approach on future projects. The approach has currently been described in project bid material in the sponsoring organization with success leading to an adapted version being used on a current project. It could potentially offer a way of assessing sustainable design options in relation to project value.

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Appendix C Not everyone loves chocolate cake

Unity is strength

Successful projects depend on much more than simply having a good site, plenty of money and a skilled design team. And while the claim that a good client is essential is doubtless true, it does not go far enough. To succeed, a scheme needs good relationships between the client and those responsible for design and delivery.

Whatever the aspirations and mission statement of an organisation may be, it is its individuals that deliver the results. Buro Happold's Phil Hampshire and Jim Crouch have been exploring a way to measure the attributes and aspirations of people in a particular team, to make the idea of delivering 'value' more than just an aspiration which everyone pays lip service to. They have developed a 'value improvement process', to ensure not only that all in the team work together well, but also to identify what everybody wants to get out of the process. Hampshire explains: 'To deliver value we need to give our clients something that fits their needs in a way that delights them. It must reflect their individualism too, after all, not everyone loves chocolate cake!'

During their research, Hampshire and Crouch came across the concept of a value survey, a way of measuring which values are most important for a group of people, and what the differences are. A spider graph highlighting the results showed that for the group at BH, the top values were 'meaning in work', learning, enjoying work, honesty and being capable. The largest deviations tended to be on the lowest ranked elements.

Hampshire and Crouch took the survey to a live schools project, and measured the aspirations relating to it. Five groups of people were asked to rank 18 different aspirations for the building – the management, teaching staff, governors, the design team and local residents.

In some areas aspirations differed widely. For example, while the design team and local residents valued direct access to outdoors, for the others it was far less critical. And whereas the teachers and governors put larger classrooms near the top of their list, it was relatively unimportant for the other groups.

The techniques used to gather the information were unusual as well, including rapid surveys carried out using Survey Monkey, and 'speed storming', which gave people just one minute to describe a problem with their existing building, followed by three minutes for the group to come up with solutions. Hampshire says this way of working might be extended to social networking sites in future. The overall aim was to break down barriers and create an atmosphere where everybody's views were treated as of equal importance. This helped to tease out results that might not always be apparent.

Crouch says that the approach 'will help the project team understand where the priorities lie'. To achieve optimum satisfaction levels it is important that the design team and clients align their aspirations before the design is completed.

The best building is not necessarily the one that wins design awards. It is the one that fulfils the aspirations of its clients and users. The process that Hampshire and Crouch have developed should help to ensure that even more buildings succeed according to these criteria.

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Not everyone loves chocolate cake

REQUIREMENT	RANK: MANAGEMENT	TEACHING STAFF	GOVERNOR	DESIGN TEAM	LOCAL RESIDENT	ALL
01 Offer more space (larger classrooms)	15	3	5	13	14	11
02 Offer dedicated specialist rooms (ICT suite, artroom, library, shower room, food tech).	8	14	14	15	14	16
03 Be energy efficient and be environmentally designed	7	8	3	7	5	5
04 Be attractive and airy offering views for all	8	8	6	6	9	8
05 Have direct access to outdoors from all classrooms	13	15	16	1	9	12
06 Be a practical and pragmatic building with flexibility for future changes, development and potential expansion	2	5	1	11	1	1
07 Have creative flair and memorable design	8	8	8	7	5	9
08 Have a garden area for pupils to grow plants/vegetables	4	5	17	1	9	10
09 Have a modern IT network and www. connectivity	11	12	15	15	5	14
10 Be easy and cost effective to maintain	4	8	4	1	3	3
11 Incorporate state-of-the-art building technologies	16	18	8	17	14	17
12 Use and demonstrate sustainable use of materials	13	17	6	13	9	13
13 Be in keeping with its setting	1	12	8	1	5	4
14 Make the most of natural resources (sun/shade, orientation, wind and views)	2	5	2	1	9	2
15 Will not date over time	6	1	11	7	4	6
16 Have a clear separation of wet and dry areas	18	15	18	18	14	18
17 Offer suitable storage facilities to provide ready access in classrooms	17	2	11	12	14	15
18 Have low running costs and be economically viable	11	3	11	7	2	7

Right Example of survey results on a school building showing ranking of the various requirements in the brief by people involved in the scheme.

Appendix D Mapping the performance of green roofs in different climatic regions: the development of a roof decision support system for use in industry

Mapping the performance of green roofs in different climatic regions and zones: the development of a roof decision support system for use in industry

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ABSTRACT

To justify the selection of green roofs, architects, engineers and clients require quantitative data, in addition to the widely available qualitative information on their benefits. This information has to be context specific with respect to climate of the site and the roof build-up. For consultancies designing buildings in numerous countries with significantly different climates, collating this information for individual projects can be problematic. This is due to the fragmented nature of the information available along with much of the data being case specific. The pressured project timeframes in industry do not allow practitioners the time to search through and access the required information, or draw inferences from case study data to make informed decisions. Additionally it is often not clear if there is any green roof guidance for the region in question. This paper presents the development of a decision support tool to inform green roof selection based on their quantifiable benefits for a particular region's climate.

KEYWORDS

Green roofs; decision support; management and delivery; global climates.

INTRODUCTION

Research on the performance of green roofs has advanced rapidly over recent years with much research documenting their diverse benefits which include improvements in roof lifespan and whole life costs (Wong, Tay *et al.*, 2003), biodiversity (Brenneisen, 2006; Dunnett, Nagase *et al.*, 2008), visual amenity (Yuen and Nyuk Hien, 2005; White and Gatersleben, 2011); noise reduction (Van Renterghem and Botteldooren, 2008; Van Renterghem and Botteldooren, 2009) and thermal and water retention performance. With the growth in green roof research there is now a significant amount of quantifiable data. This could potentially be used to justify the inclusion of green roofs on projects. However, much of this data is case specific, derived from field experiments in a certain climate for a specific green roof system. This means that generalising the data for use in different circumstances is difficult. Additionally, establishing whether the research data is appropriate for use in different situations often requires time consuming, resource intensive investigation. Unfortunately, this limits the usefulness of the research to practitioners.

To make the research accessible and useful for the design, selection and justification of green roofs, some structure is now required to assess which green roof data is appropriate for the project's context. In order to be able to transfer the conclusions and results of one study to a new design, it is essential that the climates are similar and the green roof types are also similar. Therefore, the aims of the research are; (1) to categorise thermal performance and runoff reduction data with respect to climate and roof type; (2) to develop a method to use the categorisation as a decision aid and; (3) to highlight regions and climates with little research on the performance of green roofs.

The focus of the paper is on developing a decision aid. The chosen parameters are thermal and water performance. These parameters were selected as they are highly interrelated and depend on similar attributes. These include; climate, substrate depth, vegetation type and density. Additionally there has been significant research in the thermal and water attenuation performance of green roofs meaning that a method of handling the data will be beneficial. Furthermore, these aspects are perceived as being particularly important by many authors. Kohler et al. (2002) state *"that the most obvious argument for green roofs is the reduction of surface temperatures"*. Other authors note the importance of quantifiable data on attenuation performance stating that if *"green roof installations are to become commonplace in the United States, quantifiable data that document the ability of green roofs to retain stormwater under the climatic conditions of the region must be available"* (VanWoert, Rowe *et al.*, 2005). Many authors have also emphasised the role of climate in the performance of planted roofs (Theodosiou, 2003; Sailor, 2008; Stovin, 2010; Schroll, Lambrinos *et al.*, 2011). Other key variables include growing media depth, irrigation and vegetation type and density (Dunnett, Nagase *et al.*, 2008; Sailor, 2008).

Review articles on both the thermal performance (Castleton, Stovin *et al.*, 2010) and hydrological performance (Mentens, Raes *et al.*, 2006; Czemiel Berndtsson, 2010; Rowe, 2010) have been published. This paper seeks to map both types of research with respect to climatic conditions and in relation to their key variables. In doing so it seeks to provide a decision support aid to help practitioners establish which research is most appropriate to inform their decision making. The decision aid is made up of the following parts; a map of the currently available research categorised according to climate type; summary tables outlining the key research findings of existing research and; a flow chart demonstrating how these two parts of the decision support tool can be used to aid in design and selection decisions.

METHODOLOGY

The methodology primarily involved undertaking a meta-analysis of secondary data from the literature. An updated version of the widely used Koppen-Geiger Climate Map was used to categorise the research according to climate type (Peel, Finlayson *et al.*, 2007). The maps were originally based upon the vegetation distribution for the various areas and thus are considered particularly appropriate for categorising the performance of vegetated roofs. Classifying the research according to climate type allows the results of field experiments to be generalized to projects in similar climates with similar green roof buildups relatively easily. Whilst the author appreciates that there can be local variations within the climate classification, it is considered that this will provide an improved initial indication of whether the data is transferable in the early stages of a project when information is limited.

To ensure that papers have been peer reviewed and to maximize scientific credibility, reference has only been made to journal papers. Whilst it is appreciated that research has been undertaken in many languages, the papers reviewed are all written in English. Further reviews such as Mentens *et al.* (2006) that summarise the runoff retention research from journal papers written in German would potentially be very useful for practitioners and researchers.

The research assessed includes; field experiments (FE) (experiments exposed to the external environment); controlled laboratory experiments (LE); computational and mathematical modeling (M); and literature reviews (LR).

In addition to the research being plotted on the maps, the main findings for each piece of research are summarised in tables. Main factors, such as green roof build-up (extensive/intensive), season of research, and findings are included and were selected based upon previous research which highlighted these as key factors affecting their performance (Czemiel Berndtsson, 2010). In terms of roof build-up, “extensive” is defined for the purposes of this paper as roofs with less than 150mm of substrate and, “intensive” as having more than 150mm depth of substrate. Due to space constraints the data tables are not included in the paper, however they are available upon request from the author.

A simple flow chart is proposed in Figure 1, along with two examples to demonstrate the process by which the map and summary tables can be used in parallel to help inform green roof selection by establishing which research is most appropriate.

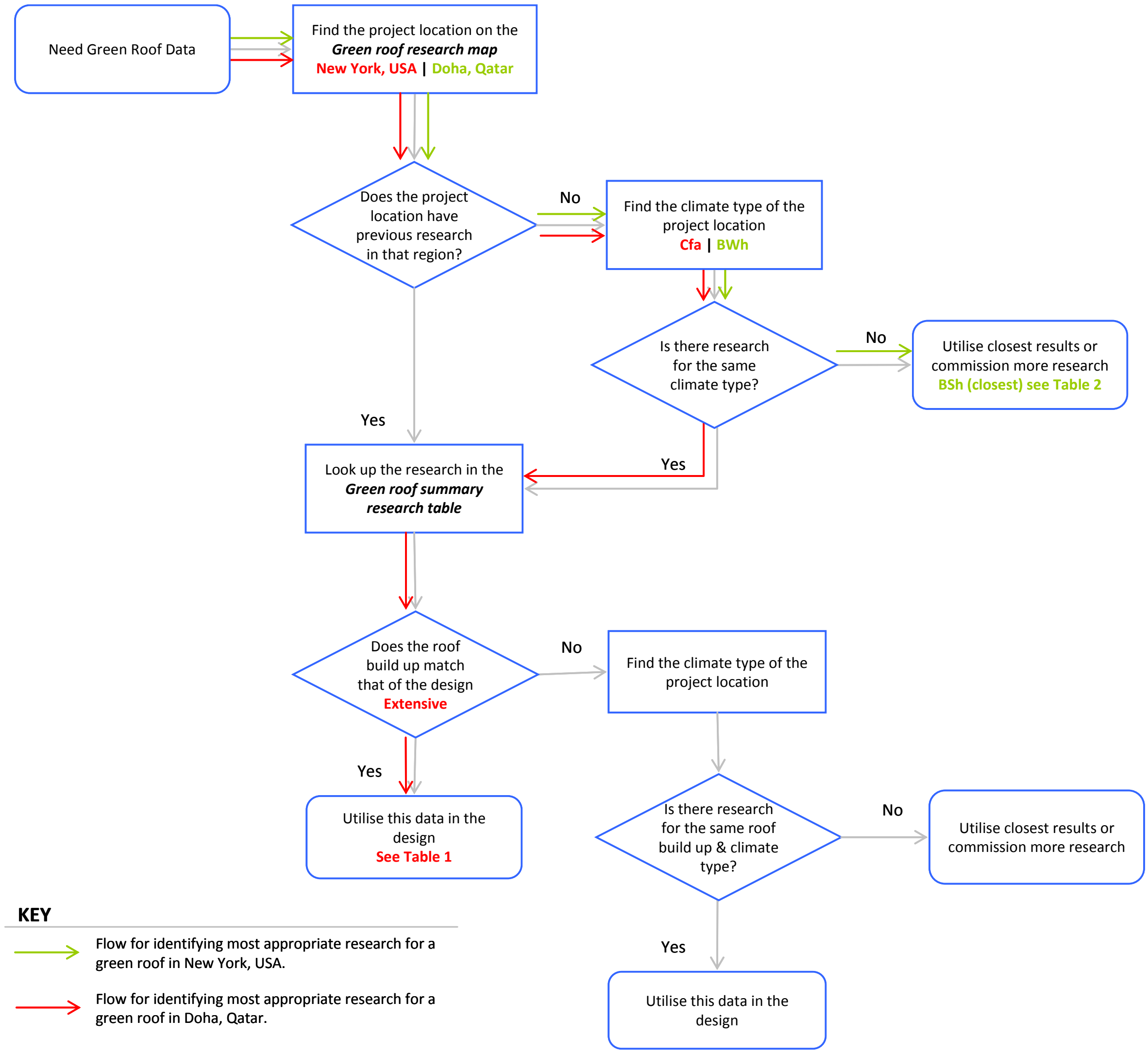

Figure 1. The simple flow chart detailing how to utilize the green roof research map (Figure 2) and the research summary tables.

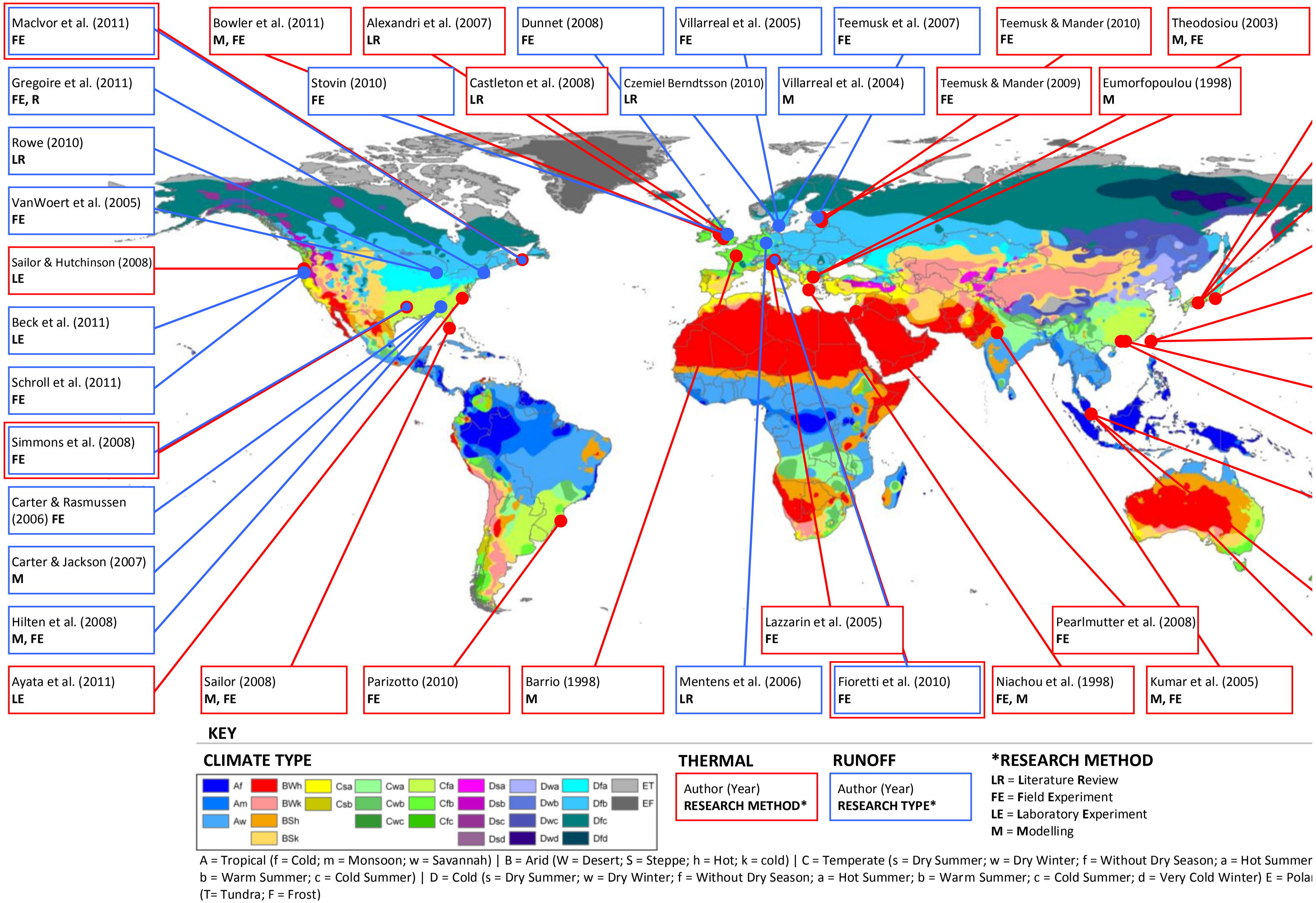

Figure 2. The green roof research map, showing the location of thermal and hydrological green roof research plotted on the updated Koppen Geiger climate classification (Peel *et al.*, 2007).

EXAMPLE RESULTS

For a project with an extensive roof located in New York, the red annotations on Figure 1 outline the process that would be followed through the flow chart. The green annotations represent the flow for selecting the most appropriate information for Doha, Qatar. Table 1 and 2 outline the results that would be returned for New York and Doha respectively. This data can then be used to inform decision making. Additionally, the tool is hierarchical in nature allowing the user the ability to see more in depth information where necessary in particular areas. For example, whilst, “intensive” / “extensive” may be an appropriate initial indication of the roof build-up, the importance of substrate type and plants is also extensively documented. Therefore if the user of the decision support wishes to find more information on the roof build-up they can simply click on this and get further detail as demonstrated in Table 3. This also demonstrates the differences in what appears at first glance to be very similar roof build-ups. Thus this level of information is important when assessing the performance in more depth.

Table 1. Example results table for green roof research that may be applicable to the design and selection of a green roof in New York, USA.

Reference	Research Type[1]	Method[2]	Study Location	Climate Type	Season	Substrate Depth	Main findings
Carter & Jackson (2007)	SWR	M, FE	Athens, Georgia, USA	Cfa	Annual	Extensive (76mm)	Hydrologic modelling demonstrated that widespread green roof implementation can significantly reduce peak runoff rates, particularly for small storm events.
Carter & Rasmussen (2006)	SWR	FE	Athens, Georgia, USA	Cfa	Annual	Extensive (76mm)	Green roof precipitation retention decreased with precipitation depth; ranging from just under 90 percent for small storms (<2.54 cm) to slightly less than 50 percent for larger storms (>7.62 cm). Average runoff lag times increased from 17.0 minutes for the black roof to 34.9 minutes for the green roof, an average increase of 17.9 minutes. Precipitation and runoff data were used to estimate the green roof curve number, CN = 86.
Feng & Meng, *et al* (2010)	T	M, FE	Guangzhou, China	Cfa	Jul (11 days)	Extensive (40mm)	Experimental results demonstrated that within 24 h of a typical summer day, when soil was rich in water content, solar radiation accounted for 99.1% of the total heat gain of a Sedum Lineare green roof while convection made up 0.9%. Of all dissipated heat 58.4% was by the evapotranspiration of the plants–soil system, 30.9% by the net long-wave radiative exchange between the canopy and the atmosphere, and 9.5% by the net photosynthesis of plants. Only 1.2% was stored by plants and soil, or transferred into the room beneath.
Hilten & Lawrence, *et al.* (2008)	SWR	M, FE	Athens, Georgia, USA	Cfa	Jan - Aug	Extensive (100mm)	The study revealed that rainfall depth per storm strongly influences the performance of green roofs for storm water mitigation, providing complete retention of small storms (<2.54 cm) and detention for larger storms, assuming the measured average moisture content (10%) as the antecedent condition.
Onmura & Matsumoto, *et al.* (2001)	T	FE, M, LE	Osaka, Japan	Cfa	Aug (23 days)	Extensive (30mm)	The roof surface temperature decreased from about 60 to 30°C during the day time, which was estimated to be followed by a 50% reduction in heat flux into the room by simple calculations.
Parizotto & Lamberts (2010)	T	FE	Florianópolis, Brazil	Cfa	Mar (7 days) & May (7 days)	Extensive (140mm)	During the warm period, the green roof reduced heat gain by 92 to 97% in comparison to ceramic and metallic roofs, respectively, and enhanced the heat loss to 49 and 20%. During the cold period, the green roof reduced heat gain by 70 and 84%, and reduced the heat loss by 44 and 52% in comparison to ceramic and metallic roofs, respectively.
Simmons & Gardiner, et al. (2008)	SWR, T	FE	Austin, Texas, USA	Cfa	Oct - Nov & Mar - Jun	Extensive (100mm)	Preliminary hydrologic and thermal profile data indicated not only differences between green and non-vegetated roofs, but also among green roof designs. Maximum green roof temperatures were cooler than conventional roofs by 38°C at the roof membrane and 18°C inside air temperature, with little variation among green roofs. Maximum run-off retention was 88% and 44% for medium and large rain events but some green roof types showed very limited retention characteristics.
Takakura & Kitade, *et al.* (2000)	T	FE, M	Tokyo, Japan	Cfa	Summer (3 days)	Extensive (140mm)	LAI up to 3 can significantly increase the cooling effect on the air space. A simulation model was developed, and the effect of evapotranspiration was taken into account. The simulated results agreed fairly well with measured values when evapotranspiration was not large, but there was some difference at high evapotranspiration rates.
Takebayashi, & Moriyama (2007)	T	FE	Kobe, Japan	Cfa	Aug & Nov.	Intensive (210mm)	In the daytime, the temperature of the cement concrete surface, the surface with highly reflective gray paint, bare soil surface, green surface and the surface with highly reflective white paint are observed to be in descending order.

[1] SWR = Storm Water Retention; T = Thermal | [2] M = Modelling; FE = Field Experiment; LE = Lab Experiment

Table 1 shows the results for climates that are similar New York’s according to Koppen-Geiger climate classification (Cfa). Some of the results will be more relevant than others. However, this provides an initial indication of the research and possible thermal and rain water retention benefits. As no results were available for Doha's climate type (BWh), the closest climate type (BSh) was selected as the most appropriate and the results are shown in Table 2. However, these results should be used with a greater degree of caution.

Table 2. Example results table for green roof research that may be applicable to the design and selection of a green roof in Doha, Qatar.

Reference	Research Type[1]	Method[2]	Study Location	Climate Type	Season	Substrate Depth	Main findings
Kumar & Kaushik (2005)	T	M, FE	Yamuna Nagar, India	Bsh	Jun	Unclear	The model is found to be very accurate in predicting green canopy-air temperature and indoor-air temperature variations (error range 73.3%, 76.1%, respectively). Cooling potential of green roof is found adequate (3.02kWh per day for LAI of 4.5) to maintain an average room air temperature of 25.7 1C. The present model can be easily coupled to different greenhouse and building simulation codes.
Niachou & Papakonstantinou, *et al.* (2001)	T	FE, M	Athens, Greece	Bsh	Jun - Aug	Unclear	During a typical summer day lower indoor air temeprature is measured in the building with the green roof, with dense sampels of measurements not exceeding the value of 30°C, in periods where the air conditioning systems were not operating. On the contrary, in the building with the green roof, the air temperature was exceeding a 30°C value and the daily temperature width was also higher. In the case of the non-insulated roofs with and without the green roof, the estimated differences of the heat transfer coefficient varied from 6 - 16W/m^{2}K. Finally for well-insulated roofs the differences of the heat transfer coefficients are much lower ranging from 0.02 to 0.06 W/m^{2}K. As a results the heat insulation performance of the green roof becomes considerable in constructions with low or no insulation.
Pearlmutter & Rosenfeld (2008)	T	FE	Be'er Sheva, Negev, Israel	Bsh	Summer	Intensive (160mm)	Covering a building's roof with soil, wetting the soil and shading the wet soil surface may provide a simple and efficient means of low-energy cooling in hot and dry climates – has been largely confirmed under the conditions of the experiment.
Santamouris, & Pavlou *et al.* 2007	T	FE, M	Athens, Greece	Bsh	Sep - Dec	Unclear	The energy performance evaluation showed a significant reduction of the building's cooling load during summer. This reduction varied for the whole building in the range of 6–49% and for its last floor in the range of 12–87%. Moreover, the influence of the green roof system in the building's heating load was found insignificant, and this can be regarded a great advantage of the system as any interference in the building shell for the reduction of cooling load leads usually to the increase of its heating load.

[1] SWR = Storm Water Retention; T = Thermal | [2] M = Modelling; FE = Field Experiment; LE = Lab Experiment

Table 3. Example of additional level of roof build-up information

Reference	Roof build-up summary	Roof build-up
Parizotto & Lamberts (2010)	Extensive (140mm)	vegetation (200mm) soil substrate (140mm) geotextile filter (10mm) gravel and pebble drainage layer (180mm) reinforced mortar (30mm) extruded polystyrene insulation (20mm) no asphalt sealer (4mm) concrete slab (150mm)
Takakura, Kitade, *et al.* (2000)	Extensive (140mm)	two roof types tested (1) ivy 150mm approx, 140mm of soil , plastic sheet, 60mm concrete roof | (2) turn 75 mm approx, 140mm of soil, plastic sheet, 60mm concrete roof

DISCUSSION

The above examples show how the map and the decision support tool can be used to reference useful data for decision making and design. Current trends suggest that research data will increase with time and thus more climate types and roof types and regions will have data on their various benefits. The following discussion is based around the third aim of the paper; *to highlight regions and climates with little research*. It is appreciated that the review is not fully comprehensive due to some articles not being accessible. Additionally the focus has been primarily on green roof literature however, literature from other fields, such as Bowler, Buyung-Ali *et al's* (2010) review of urban greening literature may also be beneficial in justifying design decisions.

Table 4. Reviewed green roof research by broad climate type and research type.

Research type	Climate type					Research method			
	A	B	C	D	E	M	FE	LE	LR
SWR	0	0	9	7	0	3	17	2	2
T	4	4	13	3	0	18	26	4	4
Totals	4	4	22	10	0	21	43	6	6

As can be seen from the research map (Figure 2) and the summary table (Table 4), there appears to be significant research with regards to the water retention benefits of green roofs occurring in Europe, and the USA, in predominantly temperate *C type* climates.

Additionally research has recently being undertaken in cold climates for both storm water retention and thermal performance. Unfortunately Tropical and Arid climates have not received much attention in relation to storm water retention. Whilst some thermal data is available for tropical regions further clarification would be beneficial, as Kohler *et al.* (2002) suggest that the potential of green roofs in these regions is large. Whilst none of the reviewed papers discussed performance in the Polar Regions, limited development occurs in these areas and thus immediate focus should be on their performance in more populated areas.

Significant research has been undertaken on extensive roof types. Research looking at more intensive green roofs would be beneficial. Unfortunately, many of the descriptions of the roof build-ups in the literature are vague which limits their usefulness when trying to utilize the results to inform roof design and selection.

Field experiments are the primary research type for the reviewed thermal and water retention research. It is hoped that the decision support tool will help practitioners identify relevant research more easily. The second most popular research type is modeling. Modeling is often conducted and validated inline with field experiments. Many of these models show high correlation with the results of their own field experiments. However, these models are not in widespread use across the industry as they are not often compatible with building simulation programs. Additionally, it would be beneficial to try the models using data from different climates types to test and document their generalisability.

CONCLUSIONS & FURTHER WORK

The framework proposed in this paper provides a quick and simple way of identifying reliable data to justify the inclusion of green roofs on building projects around the world. This could be useful to practitioners who require quantitative data at the start of a project to justify their inclusion, and coordinate the design in an efficient way. Additionally, it collates some of the existing research and identifies areas which would benefit from future study.

Through the research it was noted that most papers focusing on green roofs are seeking to gain quantitative data on their performance. However, there are very few papers looking at decision making and the delivery process on projects. Additionally, whilst the thermal and hydrological performance of green roofs is focused on here, it is important to align the performance of the design of a project with the needs of the project stakeholders. For example in order to establish green roofs on projects in locations where there is no policy encouraging or requiring their implementation, the green roof must be considered as good value by the people paying for its installation. Convincing project stakeholders of the value of green roofs must be done in ways that align with the perceived desires of those people. If the benefits can be quantified in line with those needs, the delivery of green roofs could be improved.

Beneficial future work would include expanding the framework to include other types of performance data such as, water quality, biodiversity enhancements, watering requirements, air pollution benefits, whole life costing data, aesthetic benefits and policy initiatives etc. This could then be used to holistically compare their performance with other roof types. Furthermore the framework could potentially be further developed in to an open and interactive portal that not only allows practitioners to access relevant information but allows researchers the ability to input their latest research results and findings in a standardized and accessible format. This would have mutual benefits for industry and academia. Industry would benefit from the latest information to inform green roof design and help justify their inclusion on projects. Academia would benefit from being able to align their research to meet the needs of industry.

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Appendix E Trial workshop results from Happold Consulting team

Trial workshop results from Happold Consulting team

Introduction

This summary outlines what values are and how better capturing and understanding stakeholder values can, (1) improve and align internal strategy and, (2) increase the value of client projects. A technique is then described that can be used to help capture peoples' values. This is presented with an example which outlines the results of a recent values survey and workshop; a recent research collaboration between Bath SAT and HCI.

What are values?

Values are the criteria which we use to select and justify actions and evaluate people (including ourselves) and events. The values held by individuals influence their perception of the world and, more specifically, their assessment of products and services. Hence, values frame the assessment of value. When individuals collaborate to realize a common goal, projects are formed. Individuals can subscribe to certain common values shared by others. This commonality of values across groups defines cultures.

Schwartz, a leading social psychologist, and cross-cultural researcher, generated a conceptual definition of values that incorporates five formal features. Values (1) are concepts or beliefs, (2) pertain to desirable end states or behaviours, (3) transcend specific situations, (4) guide selection or evaluation of behaviour and events, and (5) are ordered by relative importance. Values, understood this way, differ from attitudes and qualities primarily in their generality or abstractness (feature 3) and in their hierarchical ordering by importance (feature 5).

Schwartz claimed that this complex concept of a human values system can help individuals understand their own priorities, interactions with others, and their judgements and attitudes towards almost everything.

If values are expressed and shared between people a value system can emerge. This value system, if defined by the stakeholders in the context of a project, can be used to assess value and improve its delivery. For an organisation, this structure provides an understanding of how they can define organisational values and business strategy.

The Universal Structure of Values

Schwartz identified ten motivationally distinct value types that are likely to be recognized within and across cultures and used to form value priorities. Through his work he demonstrated that this set of value types is relatively comprehensive, encompassing virtually all the types of values to which individuals attribute at least moderate importance as criteria of evaluation.

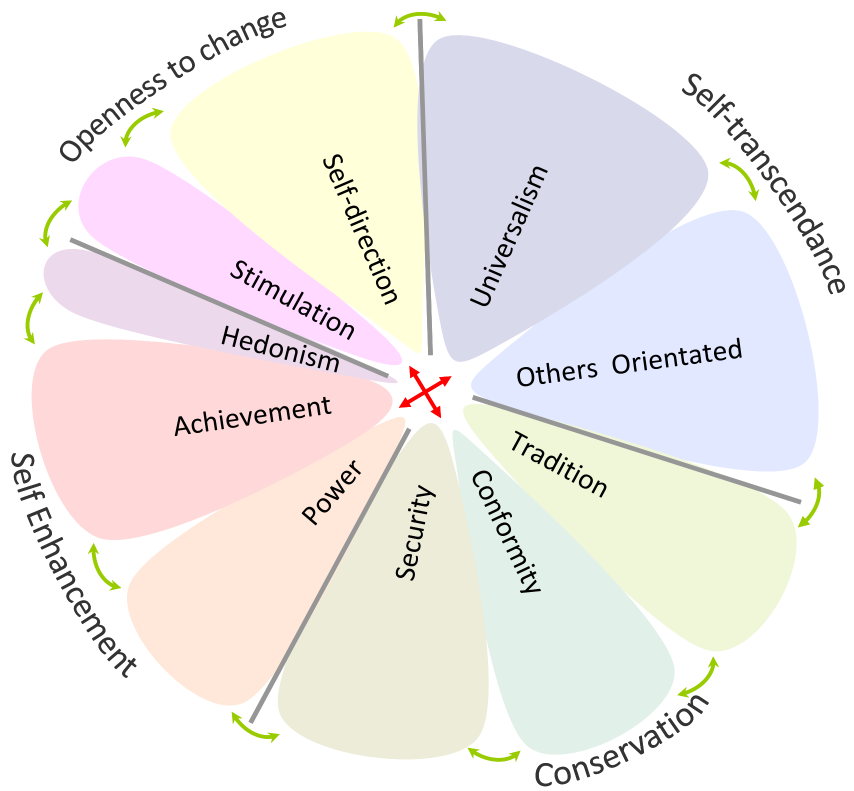


Figure 0—1 Universal Structure of Values

Schwartz's work showed that the value types could be organised into an integrated motivational structure with consistent value conflicts and compatibilities (Figure 1). Single values can also be conceived as arrayed on a continuum of related motivations. Therefore value sets adjacent to each other in this circular structure are compatible (represented by the green arrows in Figure 1). For example power and achievement both emphasize social superiority and esteem; stimulation and self-direction both involve intrinsic motivations for mastery and openness to change; tradition and conformity both stress self-restraint and submission etc.

However, the simultaneous pursuit of higher order value sets on opposing sides of the circle gives rise to strong psychological and/or social conflict (red arrows on Figure 1). The total value structure can be viewed as composed of four higher order value types, self-transcendence, conservation, self-enhancement and openness to change. These form two basic, bipolar, conceptual dimensions. The first is openness to change against conservation. It arranges values in terms of, the extent to which they motivate people to follow their own intellectual and emotional interests in unpredictable and uncertain directions, in opposition to those values that represent peoples need to preserve the status quo and the certainty it provides in relationships with others. The second is self-enhancement in opposition to self-transcendence. This dimension arrays values in terms of the extent to which they motivate people to enhance their own personal interests (even at the expense of others) in opposition to the values which transcend selfish concerns and promote the welfare of others and nature. This model has been tested to be representative through large surveys across numerous countries.

Table 2 List of Values after Schwartz (1992)

VALUE TYPE	VALUE *description*
UNIVERSALISM	**AESTHETICS** *a pleasing visual appearance, the beauty of nature and the arts*
	SOCIAL JUSTICE *understanding the needs of others to help them correct any injustices and build mutually beneficial relationships*
	PEACE BETWEEN PEOPLE *conflict-free environment*
	UNITY WITH NATURE *fitting into nature*
	WISE IN ISSUES OF ETHICS *a mature and broad understanding of life which informs action*
	EQUALITY *equal opportunity for all at work*
	BROADMINDED *tolerant of different ideas and beliefs*
	PROTECTING THE ENVIRONMENT *preserving nature*
	INNER HARMONY * *at peace with oneself*
OTHERS ORIENTATED	**LOYAL** *faithful to my friends, colleagues and associates*
	HONEST *genuine, sincere*
	HELPFUL *working for the welfare of others by giving them just reward*
	RESPONSIBLE *dependable, reliable*
	FORGIVING *willing to excuse others and to tolerate mistakes*
	SPIRITUALITY IN WORK * *emphasizing soulful matters rather than material matters*
	TRUE FRIENDSHIP * *close, supportive friends, love*
	MEANING IN WORK * *purposeful work*
TRADITION	**RESPECT FOR TRADITION** *preservation of time-honoured customs*
	HUMBLE *modest, self-effacing*
	ACCEPTING MY PORTION IN LIFE *submitting to life's circumstances*
	FAITHFUL *holding to belief*
CONFORMITY	**MODERATE** *avoiding extremes of feeling and action*
	SELF-DISCIPLINE *adherence to one's own voluntary codes of practice, self-restraint, resistance to temptation*
	POLITENESS *(courtesy, good manners)*
	HONOURING OLDER MORE EXPERIENCED OTHERS *showing respect*
	DUTIFUL AND PROFESSIONAL *meeting obligations, obedient, adhering to statutory codes of practice and legislations*
	SOCIAL ORDER *stability of a group e.g. project group or local community group*
SECURITY	**CLEAN** *neat, tidy*
	SECURITY OF FRIENDS AND FAMILY *safety and security of people closest to oneself*
	RECIPROCATION OF FAVOURS *avoidance of indebtedness*
	SOCIAL SECURITY *protection of a wide group of people to include their financial, physical and mental well-being*
	SENSE OF BELONGING * *feeling that others care about oneself*
	HEALTHY * *not being sick physically or mentally*
POWER	**PRESERVING PUBLIC IMAGE** *protecting "face"*
	SOCIAL POWER *control over others, dominance*
	WEALTH *material possessions, money*
	AUTHORITY *the right to lead or command*
	SOCIAL RECOGNITION * *respect, approval by others*
ACHIEVEMENT	**AMBITIOUS** *hard-working, aspiring*
	INFLUENTIAL *having an impact on people and events*
	CAPABLE *competent, efficient and effective*
	SUCCESSFUL *achieving goals*
	LEARNING * *enjoying the opportunity to learn, improve skills and learn new skills*
	INTELLIGENT * *logical, thinking*
HEDONISM	**PLEASURE** *gratification of desires and indulging oneself*
	ENJOYING WORK *find reward in work activities, relationships, making a contribution and having a friendly atmosphere*
STIMULATION	**EXCITEMENT IN WORK** *stimulating experiences*
	INNOVATION *varied work filled with thought, challenge, novelty and change*
	DARING *takes chances, evaluates risks, responsive to changes of plan*
SELF DIRECTION	**CHOOSING OWN GOALS** *selecting one's own purposes*
	CURIOUS *interested in everything, exploring*
	INDEPENDENT *self-reliant, self-sufficient*
	CREATIVITY *uniqueness, imagination*
	FREEDOM *choosing one's own approach*
	SELF-RESPECT * *belief in one's own worth*
	PRIVACY * *the right to have a private sphere*

What is the Values Survey?

The Schwartz Values Survey utilises the universal values model as a basis for assessing peoples' values. The 56 individual values are accompanied by a short description (see Table 1) to aid in understanding. The survey asks respondents to rate each of the 56 values "as a guiding principle in my life," using the following nine-point scale: "of supreme importance (7), very important (6), unlabelled (5, 4), important (3), unlabelled (2, 1) not important (0), opposed to my values (- 1)." Respondents are asked to utilise the full range of ratings as values should by definition be able to be rated by relative importance (values rule 5). The survey takes approximately 20 minutes to complete, and can be done anonymously.

The Schwartz Values Survey was circulated to the HCI team through paper copies and via email. 24 people responded representing a 56% response rate (Figure 2). The following analysis explores the values results of the HCI team.

Figure 3 Response rate of HCI team

The Results

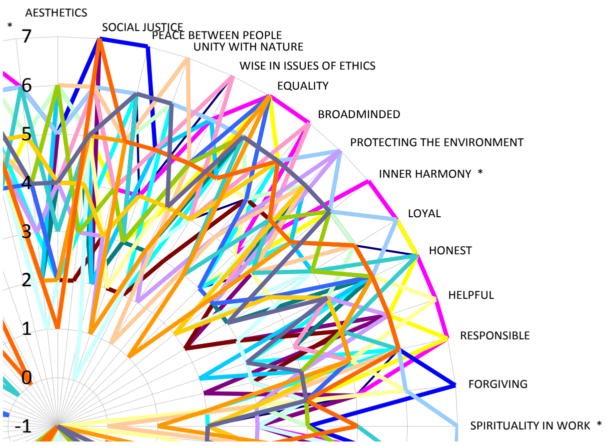


Figure 3 Individual Values for HCI team members

Figure 3 shows the diversity of individual's values in the HCI team. This is to be expected and is considered normal in any situation. This helps explain why people making decisions will often arrive at different conclusions or make different selections. Those selections will often (consciously or sub-consciously) reflect their values.

The transparent and powerful representation of stakeholder's values shown in Figure 3 can provide a useful framework around which differences of opinion and value can be explored. This richness and diversity is often difficult to achieve solely through facilitated workshops due to group politics, such as power structures. Such problems are removed through the anonymous survey based approach with the additional benefit that the opinions of large numbers of individuals can be expressed in confidence from the start.

Establishing this rich understanding at the start of the project can be useful in guiding the following dialogue, managing expectations and developing the design. This can be particularly powerful in informing decisions where compromises are required due to project constraints such as budget.

HCI Culture

Through plotting the averages of individuals' values we can start to represent a group's culture. Figure 4 shows the averages of the HCI team highlighting their highest scoring and therefore most important group values along with the values considered least important.

The values considered most important to the group tend to be around *hedonism* and *stimulation*. *Achievement* values also appear to be highly rated, however it should be noted values marked with an "*" are unrobustly located in their respective regions. With respect to the least important values to the group, there is a negative clustering around *power* which perhaps reflects the flat non-hierarchical nature of the organisation and open communication paths. Similarly there tends to be a negative clustering of values around the *tradition* value set. This corresponds well with what would be expected as, *tradition*, *conformity* and *security* which form the *conservation* dimension are in opposition to *stimulation* and *self-direction* which are generally high scoring value categories.

Table 2 Most important and least important values

Value *Value Type*	Average		Standard Deviation	
	Score	Rank	Score	Rank
MEANING IN WORK * *Others Orientated*	5.7	1	1.11	9
LEARNING * *Achievement*	5.65	2	0.88	2
ENJOYING WORK *Hedonism*	5.61	3	1.08	6
HONEST *Others Orientated*	5.57	4	1.20	13
CAPABLE *Achievement*	5.57	4	1.08	7
INTELLIGENT *Achievement*	5.52	6	0.90	4
BROADMINDED *Universalism*	5.43	7	1.08	7
INNOVATION *Stimulation*	5.43	7	0.84	1
EXCITEMENT IN WORK *Hedonism*	5.39	9	0.99	5
SELF-RESPECT *Self-direction*	5.39	9	0.89	3
PLEASURE *Hedonism*	3.17	47	2.10	55
WEALTH *Power*	2.91	48	1.76	45
MODERATE *Tradition*	2.83	49	1.72	43
RECIPROCATION OF FAVOURS *Security*	2.78	50	1.59	35
SPIRITUALITY IN WORK *Others Orientated*	2.78	50	1.70	40
AUTHORITY *Power*	2.74	52	1.76	46
PRESERVING PUBLIC IMAGE *Power*	2.04	53	1.94	52
RESPECT FOR TRADITION *Tradition*	1.61	54	1.90	51
ACCEPTING MY PORTION IN LIFE *Tradition*	1.04	55	2.53	56
SOCIAL POWER *Power*	0.74	56	2.07	54

HCI agreement

Scores from the Schwartz Values Survey can also be used to show the level of agreement amongst the individual in a group. This can be shown through plotting the Standard Deviation as shown for the HCI team in Figure 5. Values that scored a large standard deviation show strong differences of opinion between individuals in the group. Conversely scores with a low standard deviation show areas of high agreement.

The standard deviation for the highest and lowest group values are also shown in Table 2. This highlights that agreement is typically high amongst the top 10 group values. However, the least important group values tend to show the highest standard deviations representing that there is the most disagreement amongst low importance values. Values such as accepting my portion in life, faithful and moderate all of which fall into the tradition value set are shown to have high disagreement whilst having also having relatively low average scores. This shows that whilst the average tends to represent that these values are not seen as group priorities, people are generally not agreed on this as whole.

Innovation is shown to have the lowest standard deviation which represents that people are generally in agreement amongst the group on this value. Intelligent, successful, broadminded, innovation and self respect are also value's with high agreement and ranked highly amongst the groups' most important values. This tends to suggest that the highly important group values are generally shared.

How it could inform our work

The work of the values survey could impact on our work in two ways. Firstly it can inform internal strategy and the work that we decide to undertake. Does the work we do align with our values? This is important because research shows that companies with strategies that are highly aligned with employee values and collective culture tend to perform better than those that are not. Interestingly individuals that are aware of their own values also are seemingly more motivated at work even if they are not necessarily aligned with those of their organisation.

Secondly the work could be used in the project context itself to improve the delivery of value. Research suggests that, "value priorities are often tacitly held by individuals… What is more, people have a tendency to project their own values onto others by assuming that everyone perceives the world in the same way… As such, it is often only by understanding our own values, that we can start to, without bias, recognise the values systems of others." This can be important when making decisions in a project context.

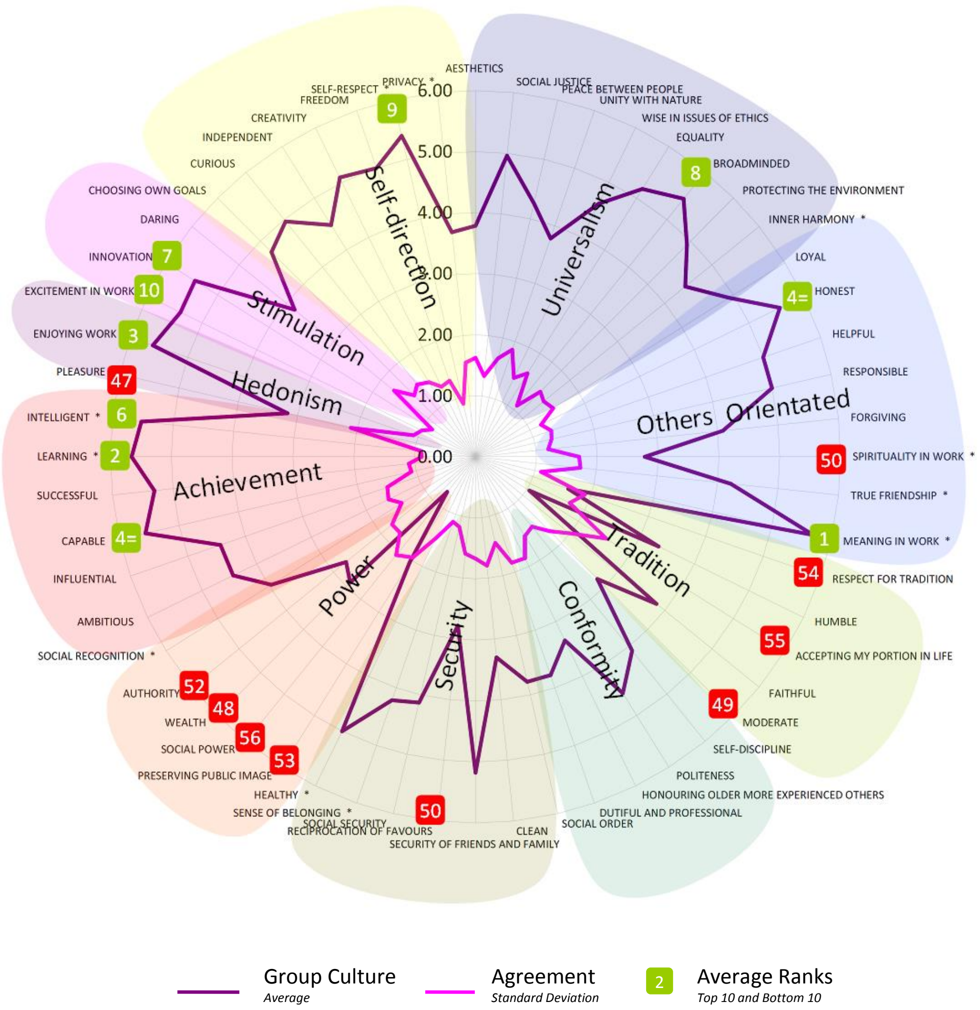


Figure 4 Averages and Standard Deviation representing group culture and agreement amongst HCI individuals

Through being aware of our own values and utilising the values survey to improve our understanding of stakeholder values in the project context we will be better placed to deliver solutions that align with what they consider of high value. It will allow us to prioritise factors that are considered of more value. However, it is worth noting that the value concept works in two directions. For example, at the recent values and value workshop with HCI it was noted that some Clients may employ us based on our organisational values and culture. In such cases Clients and their stakeholders may actually wish for us to impose our values (as well as our skills and knowledge) on a project.

In any case an improved understanding of our own and project stakeholder values through techniques such as those outlined here can help us better understand our clients, what they think is important, and identify where requirements are aligned or misaligned with stakeholder values. They can be used to inform decisions from high level strategy to detailed product or material selection. For example at a high level it can begin to help them understand their brief and prioritise requirements, highlighting the ones that are of particularly high value. At a more detailed level, if a project's stakeholders place a high important on values such as *open minded*, *wise in issues of ethics*, *protecting the environment* and *innovation*, then they will be more likely to try innovative new, ethically sourced materials, novel technologies etc.

Additionally through this open and transparent process we establish a culture of trust and can better identify methods of communicating and ways in which the project and final deliverables develop in a way that adds value to the project stakeholders.

It should be stressed however, that the values exercise must go beyond circulating the survey and analysing the results. The results should be communicated across project teams, used to highlight different points of view points, inform dialogue and find collaborative ways to progress. The ultimate aim should be to deliver the highest value solution within the project constraints.

Appendix F Pre-prep school questionnaire

[Pre-Prep School] **Values Survey**

Buro Happold

VALUES QUESTIONNAIRE

This questionnaire measures the relative importance that [Pre-Prep School] places on a pre-determined set of values. The purpose of the survey is to understand what is important to those involved in or affected by [Pre-Prep School] to allow the design team to maximise the value of the emerging design.

A value is a person's tendency to prefer one thing over another. They are distinctive for an individual or a characteristic of a group, they inform our decisions to act in a particular way or deliver a particular outcome. Values are the core elements of a culture, and identifying them will enable us to find the collective way of thinking, feeling and reacting that distinguishes the interested parties involved in the design of the [Pre-Prep School]. This questionnaire and the subsequent analysis aims to make values more visible.

The questionnaire should take between 20-25 minutes to complete. Your response will be aggregated with those of your colleagues and others with a vested interest in the development of the [Pre-Prep School] to create a Value Profile. The Value Profile will be used in a workshop to help develop a definition of what is considered of value to the [Pre-Prep School]. This will help the design team to develop high value designs for the Pre-Prep.

INSTRUCTIONS
In this questionnaire you are to ask yourself: "What values are important to ME as guiding principles in my working life, and what values are less important?" There is a list of values on the following pages.

Your task is to rate how important each value statement is for you AS A GUIDING PRINCIPLE, using a 0-6 rating scale. Where:
0 – means a value statement is not at all important, it is not relevant as a guiding principle.
3 – means a value statement is important.
6 – means a value statement is very important.
The higher the number (0, 1, 2, 3, 4, 5, 6), the more important the value driver is as a guiding principle for you.

The lowest and uppermost ratings of -1 and 7 will be given to values from the three lists. Where:
-1 – indicates the value statement most opposed to your principles.
7 – indicates the value statement that is of supreme importance to you as a guiding principle
Ordinarily there are no more than two such values for each list.

For each value statement, select the value (-1,0,1,2,3,4,5,6,7) that indicates the importance of that statement in your organisation. We are looking for your personal opinion and there are no right or wrong answers. Please read through each list of values once before completing the respective list. This will enable you to score each individual question in relation to the other value statements in the list. Please distinguish as much as possible between the value statements by using the full range of the scoring scale. You will, of course, need to use numbers more than once. Please be sure to answer all questions as honestly and as accurately as possible.
The purpose of the survey is to improve the delivery of value for [Pre-Prep]. Your results will remain anonymous.

1. YOUR ROLE IN THE [PRE-PREP SCHOOL]

Please select the stakeholder group that best describes your relationship with the [Pre-Prep School].

- ☐ Teaching staff
- ☐ Management
- ☐ Design Team
- ☐ Parent
- ☐ Local Resident
- ☐ Governor

Other please specify ____

2. VALUES LIST 1

Before you begin, please read all the values in List 1 and then choose the one that is of supreme importance as a guiding principle and rate its importance 7. Next, choose the value statement that is most opposed to the principles that guide your working life and rate it -1 (If there is no such values statement, choose the one least important to you and rate it 0 or 1, according to its importance). Then rate the rest of the values in List 1 on the scale.

SCALE
-1 opposed to my values; 0, 1 not important; 2, 3 important; 4, 5, 6 very important; 7 of supreme importance. Please utilise the full range of values.

AS A GUIDING PRINCIPLE IN MY LIFE, this value statement is

	-1	0	1	2	3	4	5	6	7
EQUALITY (equal opportunity for all at work)	☐	☐	☐	☐	☐	☐	☐	☐	☐
PLEASURE (gratification of desires and indulging oneself)	☐	☐	☐	☐	☐	☐	☐	☐	☐
FREEDOM (choosing one’s own approach)	☐	☐	☐	☐	☐	☐	☐	☐	☐
SPIRITUALITY IN WORK (emphasizing soulful matters rather than material matters)	☐	☐	☐	☐	☐	☐	☐	☐	☐
SENSE OF BELONGING (feeling that others care about oneself)	☐	☐	☐	☐	☐	☐	☐	☐	☐
SOCIAL ORDER (stability of a group e.g. project group or local community group)	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXCITEMENT IN WORK (stimulating experiences)	☐	☐	☐	☐	☐	☐	☐	☐	☐
MEANING IN WORK (purposeful work)	☐	☐	☐	☐	☐	☐	☐	☐	☐
POLITENESS (courtesy, good manners)	☐	☐	☐	☐	☐	☐	☐	☐	☐
WEALTH (material possessions, money)	☐	☐	☐	☐	☐	☐	☐	☐	☐
SECURITY (safety and security of staff and students)	☐	☐	☐	☐	☐	☐	☐	☐	☐
SELF-RESPECT (belief in one's own worth)	☐	☐	☐	☐	☐	☐	☐	☐	☐
CREATIVITY (uniqueness, imagination)	☐	☐	☐	☐	☐	☐	☐	☐	☐
RESPECT FOR TRADITION (preservation of time honoured customs)	☐	☐	☐	☐	☐	☐	☐	☐	☐
SELF DISCIPLINE (adherence to one’s own voluntary codes of practice, self restraint, resistance to temptation)	☐	☐	☐	☐	☐	☐	☐	☐	☐
PRIVACY (the right to have a private sphere)	☐	☐	☐	☐	☐	☐	☐	☐	☐
SOCIAL RECOGNITION (respect, approval by others)	☐	☐	☐	☐	☐	☐	☐	☐	☐
UNITY WITH NATURE (fitting into nature)	☐	☐	☐	☐	☐	☐	☐	☐	☐
INNOVATION (varied work filled with thought, challenge, novelty and change)	☐	☐	☐	☐	☐	☐	☐	☐	☐
AUTHORITY (the right to lead or command)	☐	☐	☐	☐	☐	☐	☐	☐	☐
TRUE FRIENDSHIP (close, supportive friends, love)	☐	☐	☐	☐	☐	☐	☐	☐	☐
AESTHETICS (a pleasing visual appearance, the beauty of nature and the arts)	☐	☐	☐	☐	☐	☐	☐	☐	☐

3. VALUES LIST 2

These values are phrased as ways of acting that may be more or less important. Once again, try to distinguish as much as possible between the values by using the full range of the scoring scale.

Before you begin, please read all the values in List 2 and then choose the one that is of supreme importance to you as a guiding principle and rate its importance as 7. Next, choose the value statement that is most opposed to the principles that guide your working life and rate it -1 (If there is no such value statement, choose the one least important to you and rate it 0 or 1, according to its importance). Then rate the rest of the values in List 2 on the scale.

SCALE
-1 opposed to my values; 0, 1 not important; 2, 3 important; 4, 5, 6 very important; 7 of supreme importance.
Please utilise the full range of values.

	-1	0	1	2	3	4	5	6	7
INDEPENDENT (self reliant, self sufficient)	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE (avoiding extremes of feeling and action)	☐	☐	☐	☐	☐	☐	☐	☐	☐
AMBITIOUS (hard working, aspiring)	☐	☐	☐	☐	☐	☐	☐	☐	☐
PROTECTING THE ENVIRONMENT (preserving nature)	☐	☐	☐	☐	☐	☐	☐	☐	☐
INFLUENTIAL (having an impact on people and events)	☐	☐	☐	☐	☐	☐	☐	☐	☐
HONOURING OLDER MORE EXPERIENCED OTHERS (showing respect)	☐	☐	☐	☐	☐	☐	☐	☐	☐
CHOOSING OWN GOALS (selecting one's own purposes)	☐	☐	☐	☐	☐	☐	☐	☐	☐
HEALTHY (not being sick physically or mentally)	☐	☐	☐	☐	☐	☐	☐	☐	☐
CAPABLE (competent, efficient and effective)	☐	☐	☐	☐	☐	☐	☐	☐	☐
HONEST (genuine, sincere)	☐	☐	☐	☐	☐	☐	☐	☐	☐
PRESERVING PUBLIC IMAGE (protecting "face")	☐	☐	☐	☐	☐	☐	☐	☐	☐
DUTIFUL AND PROFESSIONAL (meeting obligations, obedient, adhering to statutory codes of practice and legislations)	☐	☐	☐	☐	☐	☐	☐	☐	☐
INTELLIGENT (logical, thinking)	☐	☐	☐	☐	☐	☐	☐	☐	☐
HELPFUL (working for the welfare of others by giving them just reward)	☐	☐	☐	☐	☐	☐	☐	☐	☐
ENJOYING WORK (find reward in work activities, relationships, making a contribution and having a friendly atmosphere)	☐	☐	☐	☐	☐	☐	☐	☐	☐
RESPONSIBLE (dependable, reliable)	☐	☐	☐	☐	☐	☐	☐	☐	☐
CURIOUS (interested in everything, exploring)	☐	☐	☐	☐	☐	☐	☐	☐	☐
SUCCESSFUL (achieving goals)	☐	☐	☐	☐	☐	☐	☐	☐	☐
CLEAN (neat, tidy)	☐	☐	☐	☐	☐	☐	☐	☐	☐
LEARNING (enjoying the opportunity to learn, improve skills and learn new skills)	☐	☐	☐	☐	☐	☐	☐	☐	☐

[Pre-Prep School] **Values Survey**

Buro Happold

4. REQUIREMENTS

Please rate the importance of the proposed requirements for the [Pre-Prep School] from your perspective.

SCALE
-1 opposed to my values; 0, 1 not important; 2, 3 important; 4, 5, 6 very important; 7 of supreme importance.
Please utilise the full range of values.

The new Pre-Prep School should:

	-1	0	1	2	3	4	5	6	7
Offer MORE SPACE (larger classrooms)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Offer DEDICATED SPECIALIST ROOMS (ICT Suite, Art Room, Library, Shower room, Foot Tech.)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Be ENERGY EFFICIENT and be ENVIRONMENTALLY DESIGNED	☐	☐	☐	☐	☐	☐	☐	☐	☐
Be ATTRACTIVE and AIRY offering views for all	☐	☐	☐	☐	☐	☐	☐	☐	☐
Have DIRECT ACCESS TO OUTDOORS from all classrooms	☐	☐	☐	☐	☐	☐	☐	☐	☐
Be a PRACTICAL AND PRAGMATIC building with FLEIXBILITY for future changes, development and potential expansion	☐	☐	☐	☐	☐	☐	☐	☐	☐
Have a CREATIVE FLAIR and a MEMORABLE DESIGN	☐	☐	☐	☐	☐	☐	☐	☐	☐
Have a GARDEN AREA for pupils to grow plants/vegetables	☐	☐	☐	☐	☐	☐	☐	☐	☐
have a MODERN IT NETWORK and WWW. CONNECTIVITY	☐	☐	☐	☐	☐	☐	☐	☐	☐
Be EASY and COST EFFECTIVE to maintain	☐	☐	☐	☐	☐	☐	☐	☐	☐
Incorporate STATE OF THE ART building TECHNOLOGIES	☐	☐	☐	☐	☐	☐	☐	☐	☐
Utilise and DEMONSTRATE SUSTAINABLE USE OF MATERIALS	☐	☐	☐	☐	☐	☐	☐	☐	☐
Be in KEEPING WITH ITS SETTING	☐	☐	☐	☐	☐	☐	☐	☐	☐
MAKE THE MOST OF NATURAL RESOURCES (sun/shade, orientation, wind and views)	☐	☐	☐	☐	☐	☐	☐	☐	☐
NOT DATE WITH TIME	☐	☐	☐	☐	☐	☐	☐	☐	☐
Have a CLEAR SEPERATION OF WET AND DRY AREAS	☐	☐	☐	☐	☐	☐	☐	☐	☐
Offer SUITABLE STORAGE FACILITIES to provide ready access in classrooms	☐	☐	☐	☐	☐	☐	☐	☐	☐
Have LOW RUNNING COSTS and be ECONOMICALLY VIABLE	☐	☐	☐	☐	☐	☐	☐	☐	☐

Please add any requirements that you think are important in the design and development of the [Pre-Prep School] that are not included above.

Please leave any further comments in the box below.

Thank you for taking part in this survey. Your response will be used to increase the value of the design of the [Pre-Prep School].

This questionnaire is modified from work based upon the Schwartz Value Survey completed by Simon Austin, Derek Thomson, Grant Mills and Hannah Devine-Wright.

Appendix G Case study 1B stakeholder facilitation plan

Building Stakeholder Engagement: Facilitation Plan

Purpose

The purpose of the Stakeholder Engagement workshop is to understand the stakeholders' perspectives on sustainability. We want to understand their opinions and learn more about what they do and how they work. Through the workshop we hope to include stakeholder opinions in the development of the sustainability framework for the project.

Why engage stakeholders?

- To develop a well grounded sustainability framework that aligns with the needs and priorities of the project stakeholders
- To incorporate stakeholder opinions and to get their 'buy-in' to the sustainability framework, so that it becomes more than just 'lip-service' and continues into the operational phase of the project.
- To encourage mutual understanding of the reasons for inclusion of (or not) of sustainability design options/features.
- To engage their enthusiasm to change towards more sustainable ways of working and behaviours.
- To incorporate their understanding of what they do, so that the design is well aligned with their needs
- To develop a framework that can inform project decision making, on what they consider important with respect to sustainability.
- To encourage openness, transparency and provide an audit trail to project decision making with respect to sustainability.

This document

This document is facilitation plan for the workshop and outlines things to consider in preparation for and during the workshop.

Prior to workshop

The following is a list of things that we need to consider before the workshop.

Circulate invites to appropriate stakeholder groups

Invite circulated by Christine, 20/04/2012?

"You are invited to attend a stakeholder workshop on the development of a Sustainability Framework for the refurbishment and ongoing operation of the Building. The workshop will discuss what sustainability means for you as a stakeholder, the project constraints and opportunities, and will work to develop the sustainability framework in a way that reflects the values and priorities of the stakeholders.

The workshop will be held at the ###########, on the 4th of May 2012 from 11-4. Lunch will be provided. "

Confirm attendees

At present it is anticipated that between 20-30 people will be attending the workshop. It would be good to know who they are and which organisations they are from, so we can structure the mix of people in the breakout groups. Additionally, if we have any background on them and whether they have got any strong agenda's this would be good to know beforehand.

Confirm Facilitators

At present it is anticipated that the following people will be facilitators for at the workshop. Hopefully this should mean a group size no bigger than 6 or 7 stakeholders per facilitator.

- Christine Cambrook (BH) swapping between groups.
- Alasdair Young (BH)
- Lindsey Malcolm (BH)
- Damien Wines (BH)
- Phil Hampshire (BH)

Establish the role of the facilitators

What is a facilitator? Random quote from Wikipedia:

> *"The facilitator's job is to support everyone to do their best thinking and practice. To do this, the facilitator encourages full participation, promotes mutual understanding and cultivates shared responsibility. By supporting everyone to do their best thinking, a facilitator enables group members to search for inclusive solutions and build sustainable agreements" - Kaner*[3]

The facilitators role should be impartial and not take sides. Facilitators should provide structure and process so the groups can work more effectively.

In the Agenda there are prompts to initiate thought if people are 'drying up'.

Room Setup & Things to Remember

A main projector/screen to give presentation slides and introduce each session to the groups.

Whilst the room set up is a little out of our control, if possible it would be good to arrange the room as follows:

- Enough tables and space for the number of attendees.
- Tables of appropriate size for the breakout groups 6-8 people, preferably round. Each table to have the following if possible:
    - Flip chart
    - Blank paper for people to sketch on
    - Post-it notes (a variety of colours)
    - Pens (a variety of colours, not too thick or thin!)
    - Instructions for each task (can be left with the facilitators but useful to have to refer to)
- Camera to take pictures during the workshop and also capture the output put on flip charts.

Agenda

For each session, someone should be assigned the responsibility of explaining prior to the start of each session, the reason for doing the session, the intended outputs of the session and confirming that they have been understood. Facilitators should then be present during the breakout sessions to answer any questions that the groups may have.

Development of presentation to introduce the main aims of the workshop?

We need to develop a presentation that covers the following points:

- Rules regulations, fire exits etc.
- Context and background to the workshop
    - Work done to date
    - Reason for the workshop
    - Why their input matters!
- Intended agenda for the session

  - Communicate the agenda and the approximate schedule for the day
  - Explain the reason for a number of different approaches and for splitting into smaller groups
  - Highlight
- Role into group breakouts (session 1)

Development of workshop information packs

To include:
- A list of attendees to the workshop
- A brief description of the development of the project to date and the reason and benefits of THEIR involvement
- The agenda for the day
- Workshop questionnaire to assess the success of the day.
- Any information that we have developed on how we expect the sustainability specific aspects to develop in the near future.

On the day (4th May)

This section outlines a more in depth guide for facilitators to help ensure the smooth running of the day. It is written under the sections of the Agenda

Facilitators arrive (10.30 -10.45)

Purpose: Arrive before the start in order to setup room and go through any last minute concerns before the workshop attendees start arriving.

Who: TBC

Notes: PH, CC getting the train 09:15 from Kings Cross. Let us know if you are getting the same train.

Setup room (10.30 – 10.55)

Purpose: To ensure that there is enough space, and that the correct stationery is available, presentation set up as necessary.

Who: TBC

Notes: See earlier section

Agenda points as described below

Item	**Task**
1	**Arrival and refreshments (11 – 11:15)** - Meet, greet and establish who is who.
2	**Chair: Introductions and purpose of the workshop (11:15 – 11:25)** **Purpose: To outline the structure of the day, the purpose, who we are and why they are here.** **Duration: 10 minutes**

<table>
<tr><th>Item</th><th>Task</th></tr>
<tr><td></td><td>
Who: Alasdair followed by Christine

Structure & Notes:
- Key points to make are the importance of this workshop in defining how the sustainability aspects of the design progresses.
- We are here to make explicit what is important from a sustainability perspective for the stakeholders of the project (You!!)
- Your input will be considered in the development of the design, however, there are many other aspects to consider (such as the project constraints, regulations etc.)
- Overview of the structure of the day and intended outputs
- Introduce facilitators
- Distribute and highlight feedback forms for the workshop so they can be filling them in throughout the day.
- Split the group into groups... by group number in their packs.
</td></tr>
<tr><td>3</td><td>
Group breakouts: Discussion on sustainability and values (11:25 –12:05)
35-40mins

Purpose: To allow discussion amongst groups on what represents a sustainable place of work for them from their perspective?

Duration: 35-40 minutes

Who: All Attendees with facilitation as and when required by facilitators.

Expected output: Post it notes attached to flip charts?

Structure & Notes:
- Get everyone to introduce themselves, who they are, what organisation they are part of etc.
- Silent brainstorming for 5-10 minutes at the start of the session, with the intention being that individuals do not suffer from initial group think which can dominate if people latch on to specific ideas quickly.
- Additionally, it is harder for people to tie ideas back to specific individuals which can lead to conflict early if they do not agree.
- Duplication is allowed. If lots of people think that a particular aspect is important then this will be shown in the number of times it is put up.
- Get stakeholder to capture their initial thoughts as phrases which complete the following:
    o A Sustainable Place of work is...
- The facilitators can then use the post-it notes attached to the flip charts to guide the dialogue.
    o Is there anything that is not on the board which anyone thinks is important with respect to the sustainability of the Building?
    o A lot of people have stated this, does anyone have another perspective? Does everyone agree?
    o Prompts: Have we thought about the influence of behaviour?
    o Prompts: Have we thought about the design life of the building?
</td></tr>
<tr><td>4</td><td>
Guided Session: Overview of project constraints and opportunities, other approaches to measuring sustainability (12:05 – 13:50)
40-45 mins

Purpose: To bring stakeholder understanding of the project constraints and opportunities and consider this?
</td></tr>
</table>

Item	Task
	Duration: Approx 50 minutes **Who: All Attendees with facilitation by facilitators.** **Expected output: Post it notes attached to flip charts, grouped into constraints and opportunities. Also grouped into difficulty of changing constraints or exploiting the opportunity. Ideas for exploiting opportunities and overcoming constraints also included in a different colour.** **Structure & Notes:** - What are the biggest impacts/problems with respect to your current workplace? Are these related to sustainability? - How does these relate to sustainability criteria outlined by stakeholders as important as part of the first workshop session? - Can these be addressed in the design of the new building - If yes, then this is an opportunity. - If no, then this is a constraint. - Can the constraint, stopping the development of an aspect of sustainability that is important? If so, discuss ways in which this could be addressed, or accept it as a constraint. - Capture constrains and opportunities on different flip pad sheets
5	Introduction to the building (12:50 to 13:00)
6	Lunch (13:00-14:00) - Return at 14:00 for a prompt start
	General flow of sections 7 and 8: 1. What are the sustainability considerations for this project 2. Which of these can be influenced through the Building 3. Which of these are important and the main priorities to be considered?
7	**Group breakouts: What should sustainability mean for this project? (14:00 to 14:25) (25 minutes)** **Purpose: To consider earlier output captured on flip charts with respect to opportunities and constraints and what represents a sustainable work place to be discussed in relation to the project. To define categories for groups of items with similar characteristics** **Duration: Approximately 25 minutes** **Who: All Attendees with facilitation as and when required by facilitators.** **Expected output: Post it notes attached to flip charts?** **Structure & Notes:** Key questions to provoke dialogue: What are we aiming to be?

Item	Task
	- Discuss aspects considered important in sessions 3 in relation to opportunities and constraints identified in session 4. - What is possible?
8	**Guided session: Prioritisation of key themes in response to Item 6?** 14:25 to 14:50 **Purpose: To prioritise the most important aspects and inform weightings for categories on the Building Sustainability framework.** **Duration: Approximately 25 minutes** **Who: All Attendees with facilitation as and when required by facilitators.** **Expected output: Table categories ranked and post-it notes representing sub criteria in table.** **Structure & Notes:** What are the most important aspects to be addressed from a sustainability perspective? o What would you focus on first if this was you o Pair wise comparison of a variety of different things. Is A more important than B, is A more important than C, is B more important than C etc. o What is the thing which you would lose first if you had to not do something?
9	Guided session: Identifying potential conflicts and win-win opportunities in response to Item 6 (14.50 – 15:15) **Purpose: To map start considering different design options and how they relate to the issues outlined as important by the groups. Are their synergistic things that can emerge.** **Duration: Approximately 25 minutes** **Who: All Attendees with facilitation as and when required by facilitators. It is likely that facilitators might have to introduce some high level design options for discussion?** **Expected output: Relationship maps produced by the facilitators, but informed by the stakeholders** **Structure & Notes:** - Consider items, 5, 6 and 7. Look at the potential opportunities and what is most important? Do they align? Are there any conflicts. Facilitators to map and guide dialogue. See image.
10	Guided session: Stages of the sustainability process: From Concept to making a difference 15:15 – 15:40 **Purpose: To outline that this will go beyond the design phase, that someone will have to own it, and what it needs to be from their perspective.** **Duration: Approximately 25 minutes**

Item	Task
	Who: Alasdair/CC to lead? **Expected output: Notes taken by facilitators** **Structure & Notes:** - Emphasise that this is not just a design tool, needs to run through design, construction, operation, and end of life - Who should own / manage / be responsible for the framework – what about at the different stages of the project? - How can you see the framework being implemented? - What external face / reporting do you require? - Benefits of BREEAM – external 3rd party review and robustness - Drawbacks of BREEAM - How else can we demonstrate robustness and processes? - How is what we're doing better than an off-the-peg approach?
11	Chair: Next steps in the development of the sustainability framework (15:40-15:50) **Purpose: To summarise the next steps that will be followed by the team in the development of the framework** **Duration: Approximately 10 minutes** **Who: Alasdair / Christine?** **Expected output: Informed attendees. Notes by facilitators on any feedback.** **Structure & Notes:** - Highlight the questionnaire that will be circulated after the workshop. To gain a more in depth analysis. - Timeline of the progression of the project to be communicated. Individual stakeholder engagement session to be communicated. - **Report of output circulated to attendees** - Examples of sustainability frameworks developed. Flow chart of how this will happen. - Criteria development, hierarchy / ranking, measurement, management and reporting, - Next stakeholder review points - Use of sustainability framework to inform design process, construction, and eventually occupation and operation of building
12	Chair: Round up and Q&A (15:50-16:00) - Don't forget to collect all workshop material back in. Take photos of material in situ, - Collect complete surveys from people as they leave.

Appendix H Case study 1B and 1C feedback form

1.1 Workshop Feedback Form

We are always seeking to improve our engagement workshops. Your comments with respect to the sessions of the workshop will be greatly received.

How successfully do you feel we have managed to capture and discuss the sustainability perspective of your group in today's workshop? Please circle below.

Not at all	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	Completely

Please Comment

How efficient and effective do you feel the workshop has been?

Which parts did you find least interesting/irrelevant?

Have you got any suggestions on how we can improve the engagement session?

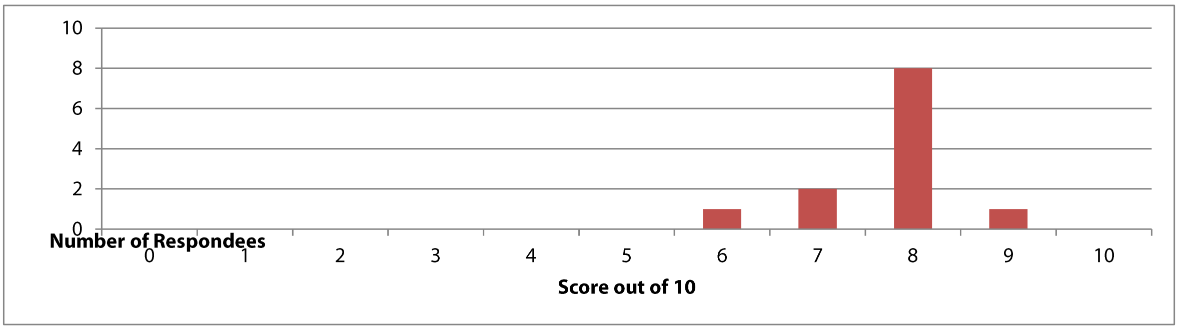
Please leave any other thoughts, opinions or specific questions regarding anything discussed in the session below (if you have specific questions please leave your email address so we can get back to you).

If you would you like to be further involved in the development of any of the project aspects related to sustainability please leave your email address below?

Appendix I Case study 1B feedback data

"How successfully do you feel we have managed to capture and discuss the sustainability perspective of your group in today's workshop? Please circle below." 0 (Not at all) – 10 (Completely)

- Average = 7.8/10. The scores are summarised in below.



Please comment [on how successfully we have managed to capture the sustainability perspective of your group in today's workshop]:

- Clear targets and session structures – sometimes facilitator voice heavy (but perhaps quiet / indecisive groups fault!)
- Varied from exercise to exercise! Fewer exercises but more time for each could have worked better
- Very interesting, particularly in introducing different user groups and allowing them to discuss and see potential similarities and differences
- Very well structured and administered
- Facilitators did a good job
- A very engaging day of discussions to establish the high-level ambitions
- Well structured
- It was good to ask for our opinions and values. A few message were missed but hopefully they are given in the sustainability process

How efficient and effective do you feel the workshop has been?

- Well run time-wise, clear goals
- Very Good in many ways and very good input and intentions but prior guidance could have helped i.e. in even more detail
- Very time efficient – but occasionally repetitive, particularly in the afternoon sessions.
- Earlier discussion quite general – more useful where more specific to [project].

- Very impressed that meeting ran to time (almost!)
- I learnt a lot. But the sessions had too much overlap so the event could have been 3 hours rather than 5.
- Efficient – yes; effective – time will tell.
- Very efficient in getting a lot of information on the table. The effectiveness will be seen at the circulation of report, design and use.
- Good
- Very effective although I thought that the breakout sessions could have been more efficient with longer clearer instructions of what was wanted from each session
- Yes – good – effective and efficient
- Very. Exceeded expectations

Which parts did you find least interesting/irrelevant?

- Final session focus on BREEAM to exclusion of other questions - would have been helpful to be led more by group and on question focus choice.
- The afternoon, strangely – it seemed to repeat much of the morning.
- Ranking exercise – less relevant
- Might have had more specific / directed guidance for some sessions?
- Some repetition – e.g. [afternoon] sessions were asking almost the same question
- Session that asked us to rank
- Presentation of building photos, but necessary for some
- Too much emphasis on prioritisation
- Rating importance of each sustainable idea at this level and stage, all seem important.
- Opportunities and constraints – maybe a bit shorter

Have you got any suggestions on how we can improve the engagement session?

- Circulate questions/agenda to attendees in advance so that people can give thought to the subjects prior to the event
- Does that mean workshops like this? If so, as I say, very detailed prior guidance and instructions/order(1) plus more orientation / priming in session.
- Use of sticky colours to signify specifics
- Longer needed (double) for summing up time of each feedback from groups

- We should have focused on outlining objectives for achieving a sustainable work place. Slightly wary of project team for defining these objectives for us.

Please leave any other thoughts, opinions or specific questions regarding anything discussed in the session below (if you have specific questions please leave your email address so we can get back to you)

- Thank you – I thought this was an interesting and valued session – please take comments above as constructive feedback
- It would have been good to gain a broader overview of possible sustainable interventions that are extant of work; examples which could help our thinking.
- Some more details would have been useful to help us make decisions / see things differently.
- Excellent table facilitation by [facilitator]
- I hope to be involved in further reports. Very interesting. Hopefully you found it useful.
- Excellent facilitator

Appendix J Case study 1C results

1 Introduction

Purpose of Workshop

The purpose of this workshop was to understand the stakeholder perspectives on sustainability in relation to the <Project name>. The workshop was an opportunity to help the design team understand the stakeholders' opinions on what is important from a sustainability perspective and also learn more about what the different stakeholder groups do and how they work. It was also an opportunity to understand the opportunities and barriers with respect to sustainability for the project, and the relationships between various issues. It is intended that this understanding can then be integrated into a project specific sustainability framework which adds value to the building and its occupants when they move in.

Through this we hope that the sustainability framework will:

- be well aligned with stakeholder needs and priorities
- be developed to be more than just 'green wash'
- be continued past the design phase and through to the operation of the building
- encourage openness, transparency and provide an audit trail to project decision making with respect to sustainability
- be a model which will inform decision making with respect to what is important for the users of the proposed building

Attendees

The following people representing their respective organisations attended the workshop. The group number represents which group each stakeholder representative was allocated, and is important when considering the output from those groups. Groups were allocated to try to ensure diversity in each group, and that sustainability was considered from several different perspectives in each case.

<attendees list removed for confidentiality>

Intended outputs and outcomes

The intended outputs from the workshop were a series of flip chart sheets which captured the stakeholders' thoughts on what should be considered with respect to sustainability for the <project name>. Through dialogue in the workshop and post workshop analysis undertaken by the design team a project specific sustainability framework will be developed. The intention of the sustainability framework is to inform project decision making in relation to value and sustainability. The workshop aimed to understand the priorities of the stakeholder groups so that the design team can use this understanding to inform decision making as the design progresses.

Intended wider benefits of the workshop included bringing the design team and stakeholders closer together to develop a mutual understanding of the project and address the most appropriate ways to advance the sustainability aspects of the design together. The workshop was developed to encourage open, collaborative group sessions, each with a Buro Happold facilitator to capture the output. In order to achieve some coherent output across groups, each session was structured and the intended deliverable for each session was explained before each session started.

The outputs of this workshop are summarised under each of the following sections. In the interests of transparency, the raw images of the outputs of the workshop are available on request. However, only some images are included in the report. Additionally, the raw data for each group was captured and analysed individually for each group, before been collated across groups and summarised for each section. Diversity and differences of opinion are highlighted where appropriate as areas which require further exploration.

Structure of this report

The workshop was structured around the below sessions. All sessions are discussed in its own section in this report. In each section we explain the:

- **Purpose and structure** of the session
- **Output** of the session
- Our **analysis of the output**
- **Key points and findings** from the engagement exercise

In addition to discussing the sessions individually we have also included a summary section that considers the output across the different agenda items as whole, and concludes how these should be incorporated into the development of the project specific sustainability framework.

Workshop Sessions

Table 1: Workshop Sessions

Session	Purpose
1. A Sustainable Building Is...	To generate lots of ideas about what a sustainable building for the <project name> might consist of.
2. Opportunities and Constraints	To utilise stakeholder understanding to capture the opportunities and constraints for the project
3. Importance vs. Influence	To consider stakeholder opinions on what is important for the project and their perceived ability to be addressed by the design team
4. Relationship Mapping	To understand the relationships between different issues and whether they are positively or negatively linked

1 Session 1: A Sustainable Building Is...

Purpose & Structure

This session had the purpose of understanding what represented a sustainable place of work for the workshop stakeholders. The session involved splitting the stakeholders into four groups. Then, after introductions each group was asked to undertake 5 to 10 minutes of silent 'brainstorming'. Their task during the brainstorming session was to capture ideas through completing the sentence, "A sustainable place of work is..." These ideas were then placed on flip-chart boards and dialogue proceeded between the stakeholders. The initial part of the session was silent to avoid group think and establish a wider range of ideas without critique.

After this initial brain-storming session the facilitators aimed to understand whether the initial output was comprehensive. Additionally, where people had similar ideas, it was discussed whether this reflected the importance of the ideas or merely was because they were obvious considerations. Discussion around the ideas also allowed grouping of similar ideas into themes. It was intended that this would provide a start to developing a shared understanding around which sustainability could be discussed for the group.

Output

The output of the session included a series of flip chart sheets from each group containing their ideas on what sustainability meant to them individually and collectively as a group. The facilitators aimed to also categorise ideas that arose from the silent brainstorming session as well as capture thoughts from the dialogue that were missed during the silent brainstorm. The output images for each of the groups are shown below and formed the starting point for the analysis after the workshop.

Figure 1: Group 1: A sustainable building is... output

Figure 2: Group 2 : A sustainable building is... output

Figure 3: Group3: A sustainable building is output

Analysis Method & Results

The first stage of the analyses involved initially capturing all the output from the session in a database and undertaking an automatic content analysis.

Figure 4: Word cloud of words from post-it notes (size represents their proportional usage)

This was then complemented through the analysis team grouping the output of the workshop into themes that align with common environmental and social sustainability considerations. Where it was considered that the comments did not fit into the standard sustainability considerations a new theme was created and populated accordingly. These generally built up a set of themes that were highly related to value for the <project name> as well as sustainability. The typical sustainability considerations are shown in Figure 5 and project specific value themes are shown in Figure 6. These themes and their representative colours are used consistently through this report. The raw data that was used in the analysis is included in the Appendix A for transparency (for each group) and can be related back to the images captured from the workshop (available on request). After analysing the content of each group, the results were collated for all workshop attendees.

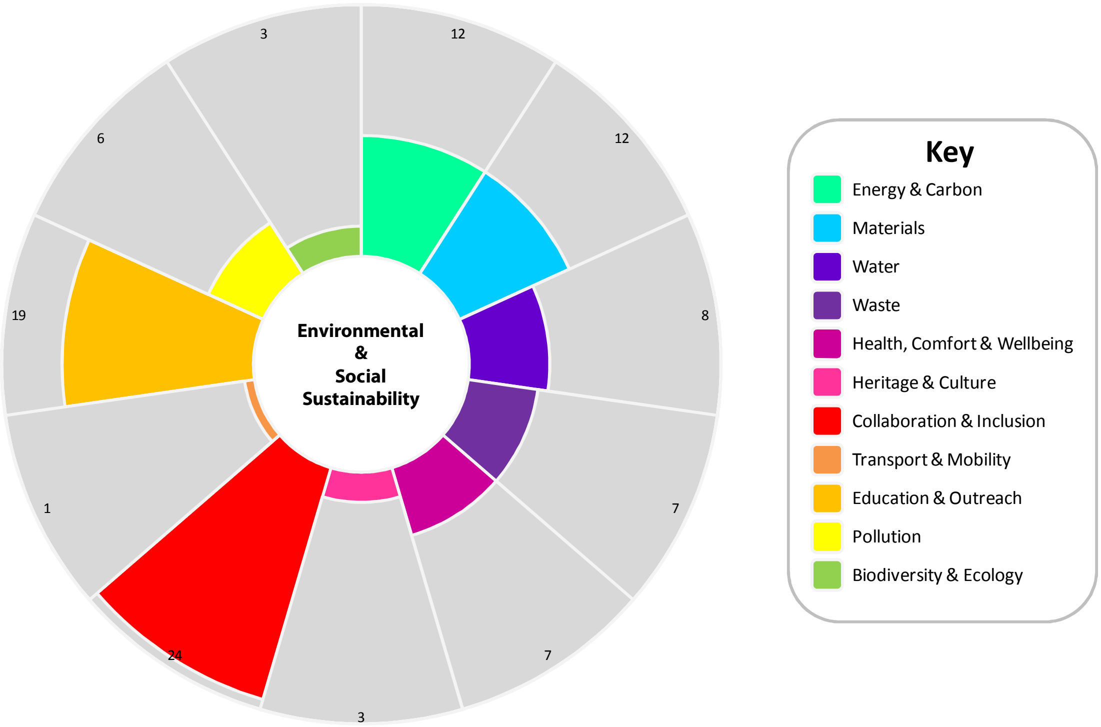


Figure 5: Sustainability Considerations*

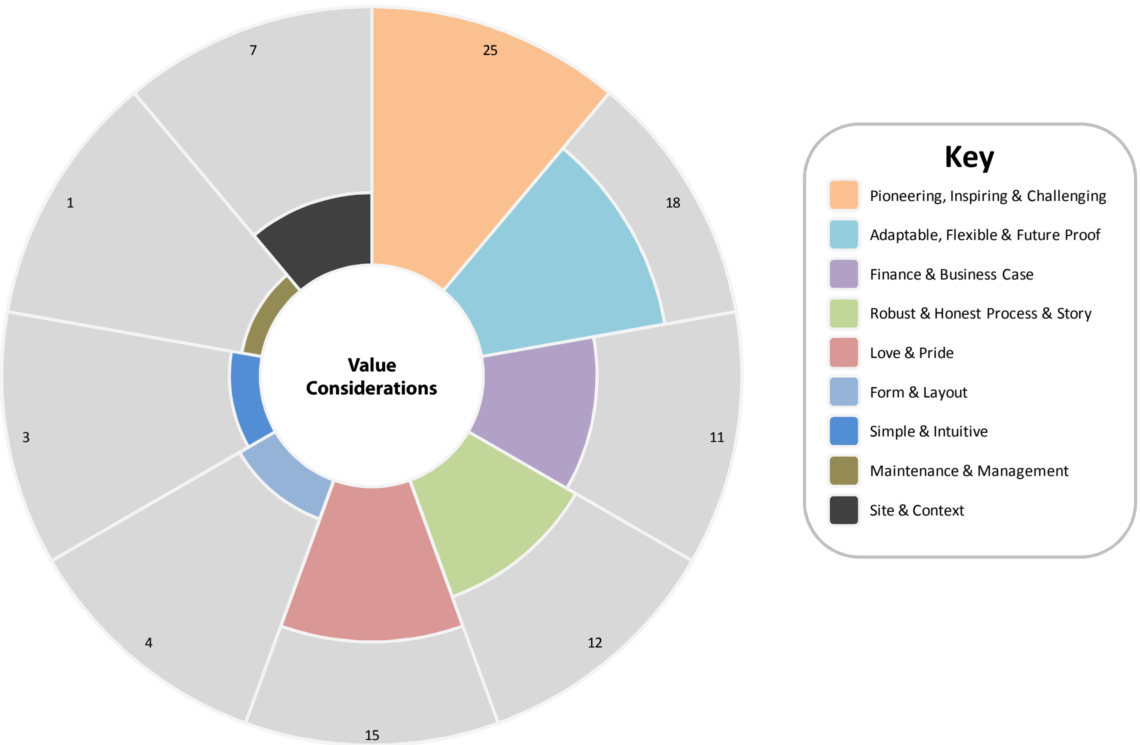


Figure 6: <project name> Project Specific Value Themes for Consideration* Summary & Key Points

* Numbers on images represents the number of post-its related to identified themes

From Figure 5 it can be seen that the most discussed sustainability themes are *“Collaboration & Inclusion”* (24 occurrences) and *“Education & Outreach”* (20 occurrences). This aligns well with the purpose of the <project name> with respect to creating a collaborative and educational environment. Additionally, these are not aspects that are traditionally considered through standardised environmental sustainability frameworks such as BREEAM. Therefore the development of a bespoke sustainability framework for such aspects may be beneficial.

Energy & Carbon, Materials, Water and Waste considerations were generally less discussed than might be expected. For example the number of times they were mentioned specifically in post it notes, did not reflect the weighting given to such issues in BREEAM. This does not necessarily mean they are not important for the project, but may just mean that the stakeholder considered these standard issues that would be addressed through BREEAM. Additionally, it is worth noting that where a post-it note referred to resources in general and specifically which resources they were referring to was not made clear, this typically meant that they were categorised under several resource themes such as Energy & Carbon, Materials, Water and Waste.

Transport and Mobility were not discussed in significant depth in this workshop, with only one post-it note referring to this explicitly. This maybe something that requires more consideration at this stage, especially if large numbers of people are expected to attend the <project name> education facility or visit the project.

Less typically considered themes included, Biodiversity & Ecology along with Heritage & Culture. This again maybe an implicit desire for the project, and if so should be discussed in more depth.

It is intend that the sustainability wheel can be used as a high level framework around which discussions with respect to environmental and social sustainability can be considered.

Figure 6 shows the project specific value themes that emerged from the post it notes. As these themes emerged from the session and are not typical considerations for all projects. A brief description of what each theme includes is given below.

Pioneering, Inspiring & Challenging: Where the analysis team thought that a phrase was intended to mean pioneering, inspiring, challenging or beacon of change then they were classified as belonging to this theme. Such phrases included a sustainable building is... *“a celebration of power that collective effort can achieve”*, *“an inspiring project full of new and exciting experiences”* and *“catalyst for industry change”.* As being pioneering can be expensive and time consuming, future dialogue should focus on in which areas the project seeks to be pioneering in as this will allow the stakeholders and wider project team greater ability to incorporate this into the progressing design.

Adaptable, Flexible & Future Proof: This was a strong theme that emerged from the post-it notes. Essentially, it is desired that the project should be adaptable and flexible. Whilst, the words were used interchangeably in the workshop, definitions of these two terms should be clarified across the design team as the project progresses. More work is required to understand the balance between a ‘big shed’ approach, tailored to the most possible uses, and ‘tight fit functionalism’. Additionally, the time frames over which changes might need to be made should be assessed for different systems. It might be useful to consider Brand’s (1994) layers in future session to begin to define which aspects are required to change and over what time frames.

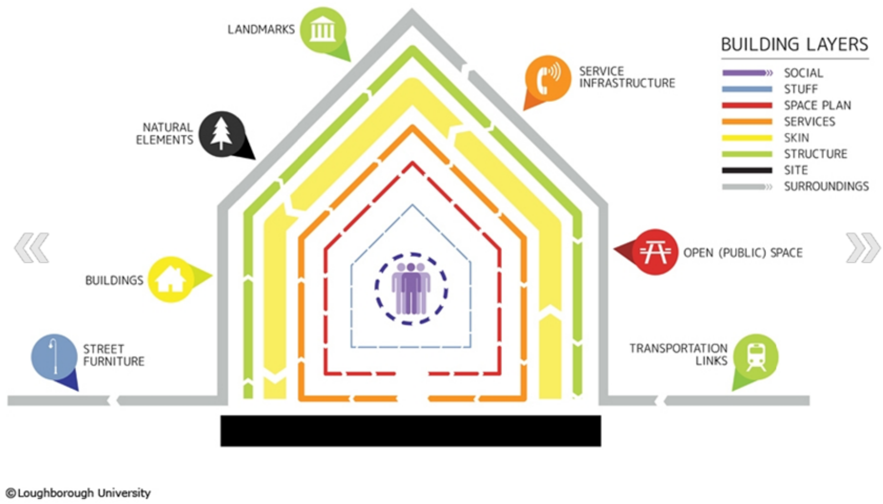


Figure 7: Brand's Layers - Copyright Loughborough University

Finance & Business Case: Comments were classified into this theme if they mentioned cost or business case, in any sense.

Robust & Honest Process & Story: The process of project delivery and the accompanying story to the sustainability and value aspects of the project occurred in several post-it notes. Robustness and transparency were often key considerations. This demonstrates the need for sustainability to be explicitly considered and communicated through the process. Next steps in addressing this should be to think about what process would be best for doing this, and consider the development of ways of assessing progress towards key criteria. Whilst it is not always necessary to quantitatively measure softer more human issues of sustainability, a qualitative way of assessing progress, and achievement in such areas can still be defined.

Love & Pride: This theme relates to aspects which were again aspirational and related to a great experience for the user of the <project name>. They included comments such as, *"a place of beauty and learning, that people want to return to"*, *"something that endures, remains useful and well loved over time",* and *"wanted and needed"*. Such comments were generally also classified into other themes, but were typically high level. Therefore more work is required to define aspect which it is considered the stakeholders will love and have pride in.

Form & Function: There were only a few comments relating to the theme Form & Function. However, it was considered an important category as the building has to house potentially many different use types. More effort is required to understand the functions required for different aspects to allow the design team to progress with more certainty and achieve an appropriate amount of flexibility in the rooms.

Simple & Intuitive: Related to maintenance & management (see below) and the way in which the building is used in general. Comments classified into this theme included, "simple to use", "user friendly", and a "project that aims to be easy to manage and one without huge expenditure"

Maintenance & Management: Only mentioned on two occasions but analysis team consider that this requires further consideration if sustainability is going to go beyond the design process.

Site & Context: Post-it notes in this category generally referred specifically to the <project name> Project Site or Context. This included regional considerations such as, “local materials and workforce”, or site specific aspects such as, “sits comfortably within its setting... becomes part of the landscape or complements the place.”

The analysis of the workshop provides a summary of how different themes were discussed in relation to environmental and social sustainability themes (Figure 5), and project specific aspects relating to both value and sustainability (Figure 6). It is hope that the output can be used to provoke dialogue and it is intended that during the next phase of engagement that these areas can be discuss in more depth and what represents success can be defined. Then the design team in collaboration with the stakeholders can begin to define meaningful metrics to measure the success of the progressing design in these areas.

2 Session 2: Opportunities & Constraints

Purpose & Structure

This session was designed to understand the constraints and opportunities that different stakeholder groups have in trying to improve the sustainability of the place in which they work, so that this understanding could be incorporate into the development of the sustainability framework. It was considered that trying to think about the issues from two different perspectives would provoke thought and allow creative ways of addressing issues. The workshop participants were also asked to share their ideas on how the constraints or opportunities they identified could be respectively reduced or exploited. The image below represents the intended output of the sessions.

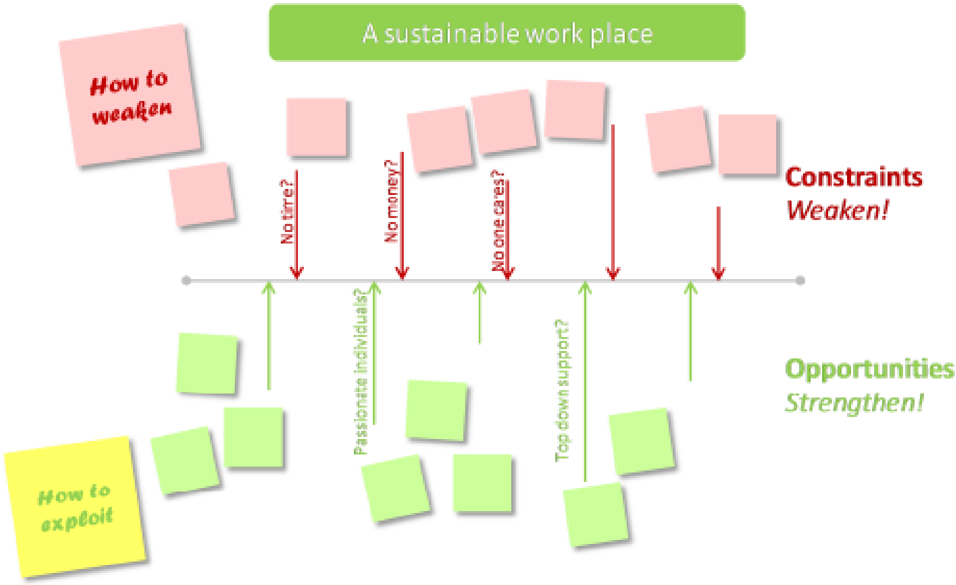


Figure 8: Project constrains and opportunities - Intended structure of output

Output

The structure of the session was intended to encourage stakeholders to think about the problems and issues from both a positive and a negative perspective. However, one person's constraint could be seen as another's opportunity and this was reflected in the output of the exercise. Therefore the output of the exercise, rather than forming a 'strict' 'force field' model often constituted a list of considerations, sometimes (but not always) with a positive or negative perspective (see Figures 10 to 12).

Figure 9 Group 1: Opportunities & Constraints output

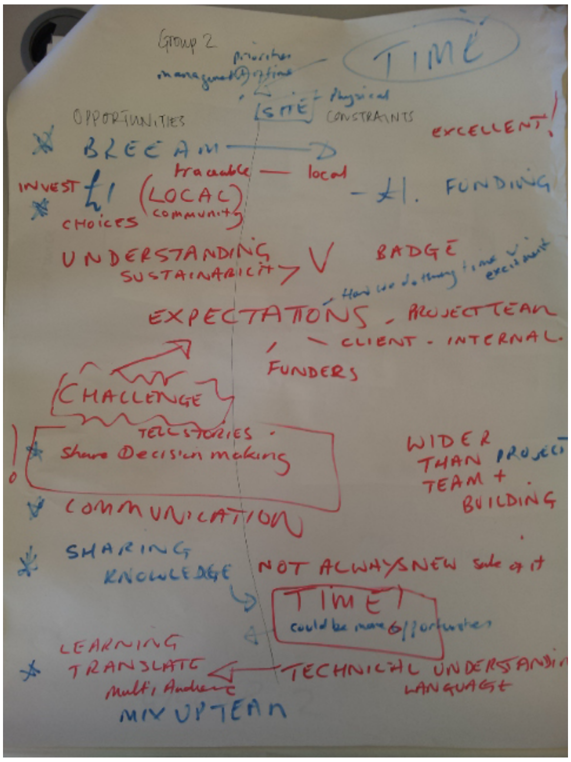


Figure 10: Group 2: Opportunities & Constraints output

Figure 11: Group 3: Opportunities & Constraints output

Analysis Method & Results

The method for analysis of the output of this session was to first consider each group individually, and then summarise and collate the output for the group as a whole. The analysis involved grouping similar opportunities/constraints into themes, additionally where possible, opportunities were directly related to a constraint were placed opposite each other. Where similar opportunities were identified by different people/groups this was captured by placing a number next to that consideration which represents the number of times this consideration was mentioned in the output of the workshop.

		Opportunities	?	Constraints	
Finance & Business Case		Cost (within budget)	Funding requirements	Cost	2
		Investment			
		Money spent well	50% public funding	Specific ties	
		Exploit the image of Eden	Manipulate wording to secure funding		
			Legislation!	Planning	
		Time (could be an opportunity	Long term ownership	Time (quicker for traditional construction than sustainable construction)	4
				Indecision and procrastination	
Story & Process		Traceable		Not always new for the sake of it	
		Tell stories			
Collaboration & Inclusion		(Local) Community		Wider than team and building	
		Understanding sustainability		Vs. Badge	
		Challenge expectations	Expectations (project team, client, funders)	Preconceptions	
		Formalise ties with Eden to ensure the most of these ties			
		Share decision making	Tribal leader	Buy in from leadership (highest level)	
		Communication			
		The right design team			
		Skills Co-ordination			
		Multi Audience			
		Mix up team			
		Technical understanding		Understanding	
	2	Utilise the pool of knowledge of Eden (Cross discipline)			
		Creative nature of Eden			
Adaptable, Flexible & Future Proof		Innovation, uniqueness, flexibility			
		Flexibility (loose fit, long life)		Uncertainty - what are we future proofing for?	
Education & Outreach		Spread the word, wider shared learning			
		Sharing knowledge			
		Learning			
		Partnerships with horticulture & training		How do we do this on top of what we are doing? Eden Pressure	
		Up skill learners before built - college			
Site & Context		Link to Eden site		Physical footprint - limitations of size of site / location	
		Cycle links		Location - transport	
		Parking spaces we can use		Local availability of materials	
Miscellaneous		BREEAM		Wanting BREEAM Excellent	
				Inclusivity and banning PVC (which is more important?	
				Tradeoffs	
				Weightings	
				Penalties for local materials	

Figure 12: Opportunities & Constraints Analysis

Summary & Key Points

Figure 12 shows that the main themes emerging from the opportunities and constraints exercise, were related to, *'Finance and Business case'*, *'Story and Process'*, *'Collaboration & Inclusion'*, *'Adaptable'*, *'Flexible & Future Proof'*, *'Education & Outreach'*, and *'Site & Context'*. Aspects which didn't fit into a specific theme were grouped into a miscellaneous category.

The theme, *'Finance and Business case'* included considerations such as cost and funding. Whilst cost is seen as a constraint it was also considered as an opportunity by one group. Time is also mentioned as a constraint on four separate occasions during the exercise and was categorised in this theme. This reflects the speed of progression of the project.

Also emerging as an opportunity under the theme *'Story and Process'* were traceability and the opportunity to develop and tell strong stories with respect to the building. The process of undertaking this workshop and developing a bespoke sustainability framework should help maximise these opportunities for the project.

'Collaboration & Inclusion' was the category that received the most focus from the output of the session. Opportunities were focused around utilising the existing pool of knowledge of Eden developed through past projects, and also establishing a collaborative approach where decision making is shared. However, concerns were raised about the lack of buy in from leadership at the highest level and this is currently seen as a constraint. This should be addressed immediately, and future engagement workshops could provide a good opportunity to engage them in the process.

'Technical understanding' was raised as an opportunity for the project, however 'understanding' was also raise as a constraint. This may refer to understanding in areas of what the project is trying to achieve as it emerged that there is some confusion on this. This should be explored in more depth by the client team and wider stakeholders immediately and captured clearly to allow the design team to progress.

'Adaptability, Flexibility and Future Proof' again emerged as a theme and whilst it was seen that there was a real opportunity to develop an innovative and flexible building, it was highlighted that there is uncertainty under exactly what we are future proofing for. Again this demonstrates that there is less understanding on this issue and this should be addressed immediately.

Opportunities such as '*sharing knowledge', 'spreading the word'* and *'learning'* were classed under the theme *'Education and Outreach'*. The constraint that emerged under this asked the question, *'How do we do this on top of what we are doing?'* Additionally, an interesting opportunity that has emerged from the engagement sessions is the prospect of engaging college students in the building of the <project name>, with the opportunity to up-skill them through the process. This also aligns well with issues emerging in the 'Process and Story' theme if well documented and traceable as it will providing a good example of how a project should be design and constructed.

Under the theme *'Site & Context'*, opportunities include the ability to use existing parking spaces, and also to develop cycle links to the site. Constraints with respect to this theme include the limitations of the site and the physical footprint of the proposed building. Local availability of materials also was also considered a constraint of the site. This may have been in reference to BREEAM and the lack of local suppliers of accredited materials, as the site has actually has some strong opportunities for sourcing certain materials from within the site boundary.

In the Miscellaneous category, BREEAM was classed as an opportunity for the project by one group whilst been considered a potential constraint by another. Issues with the measurement of sustainability such as tradeoffs and constraints were also referenced as a constraint. These should be considered carefully to ensure that they are appropriately developed through the assessment framework, and tradeoffs are well balanced and accounted for through the design process. Again an explicit framework through which these decisions can be made which is weighted appropriately for the project specific issues will help address these perceived constraints.

3 Session 3: Importance vs. Influence

Purpose & Structure

This workshop session was structured to consider which aspects were most important from a sustainability perspective and also consider which of those aspects the design team could influence. It was also hoped that the session could be used to start to develop a common understanding of what might be possible through the design, but also consider which issues would have to be addressed by the <project name> stakeholders through the design life of the building.

Stakeholders were asked to organise their thoughts in the following manner.

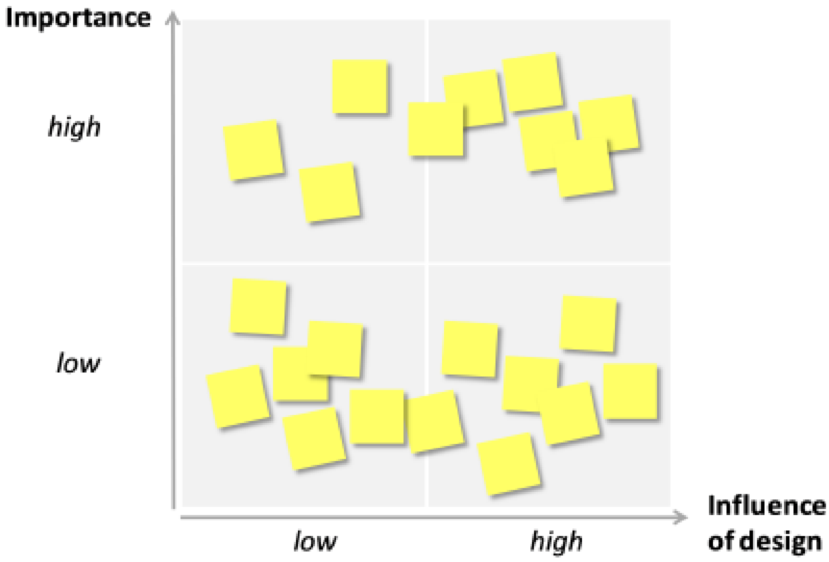


Figure 13 Intended output of the Importance vs. Influence Section

Output

The output included lots of considerations categorised into the quadrants on the boards. However, there were some issues with respect to being able to select the most important issues, and also which issues were more influenced by the design. This meant that the output was often focused around the top right quadrant (issues which were classed of high importance and highly influenced by the design). Examples of the output achieved from the session are included below.

Group 3 considered issues that were important and influenced by the users and not necessarily the design team as part of this exercise. Therefore their output is not considered in the analysis of the group as a whole.

Figure 14 Group 1: Importance vs. Influence output (design team)

Figure 15: Group 2: Importance vs. Influence output (design team)

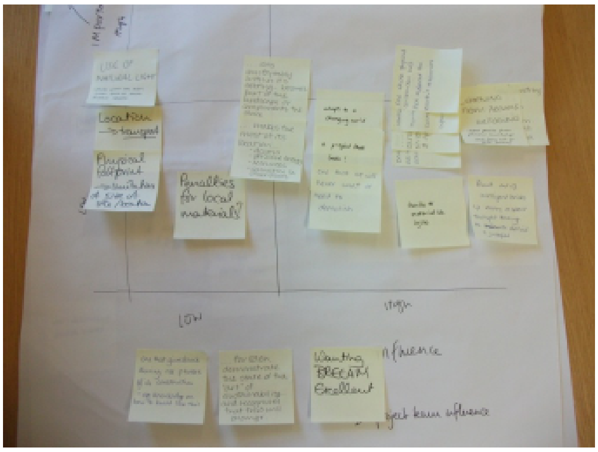


Figure 16: Group 3: Importance vs. Influence output (design team)

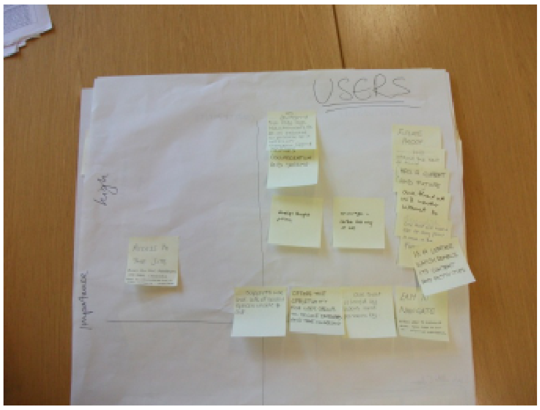


Figure 17 Gropu3: Importance vs. Influence output (users)

Analysis Method & Results

The analysis in this section involved capturing the output of the session, and giving the output items a score for both importance and influence on a scale from 1 to 10. This was done after the workshop by the analysis team in relation to where the post-it notes had been placed on the flip chart grids. Whilst some items had been placed off the grid to emphasise their importance, these were given the highest importance/influence by the analysis team, and then the rest were distributed accordingly. Additionally, each item was allocated a theme that was assumed to be the most relevant for each item respectively. This was to allow the design team to see if some themes were emerging as more important and further develop the understanding from the output of the first session. Each group was analysed individually and then the results were collated to show the results of all the groups as a whole. This can be seen in Figure 18. Figure 18 is split into quadrants, representing high/low importance vs. high/low influence of design. The below commentary will discuss aspects which occur multiple times in relation to their importance and the influence of the design. The original content of the post it notes outlining which each number represents is shown in the key on the following page.

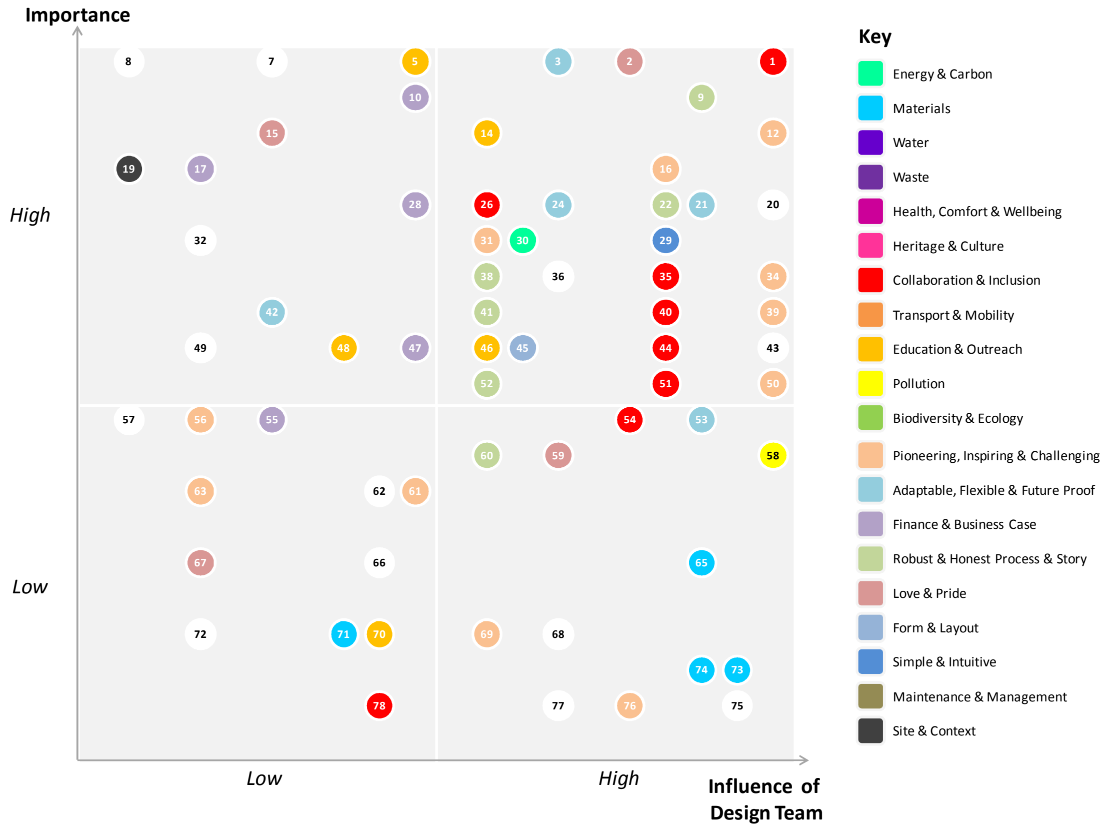


Figure 18: Importance vs. Influence Results (key on next page)

Ref.	Group	Consideration	Importance	Influence
1	1	Buy in from leadership (highest level)	10	10
2	1	A place of beauty and yearning that people want to return to	10	8
3	2	Multi-faceted / Future proof	10	7
4	1	Able to demonstrate value behind £££ by showing benfit to [all]	10	5
5	2	Makes us question why we do things the way we do - expediency, lowest cost, that the way we always do it. Best values not best value	10	5
6	1	Something we can learn from	10	3
7	2	Meeting the clients needs	10	3
8	1	Planning	10	1
9	1	Jobs / carbon / ... Able to provide real metrics that can demonstrate the power of its worth	9.5	9
10	2	Considers that the project starts with a £1 and money is an important sustainable resource, it how and where the pound is invested that is important - ist influence is key - without it no project	9	5
11	1	An inspiring project full of new exciting experiences	9	10
12	2	Aw-inspiring (attractive)	9	10
13	1	Iterative, evolving, supporting facilitating	9	6
14	2	Understand how building works (3 years)	9	6
15	1	Where things beyond your wildest dreams can happen	8.5	3
16	2	Provides a forum or catalyst for change how we build things, how we work, how we use resources, how we learn, how we live	8.5	8.5
17	1	Wanted and needed	8.5	2
18	1	Spread the word	8.5	1
19	2	Effective use of the site and its geography	8	1
20	2	inviting (people-friendly)	8	10
21	1	Flexible, adaptable, Darwinian	8	9
22	2	##### name - does what it says	8	8.5
23	1	Able to adapt	8	7
24	2	Flexible	8	7
25	1	Efficient with all resources	8	6
26	2	Collaborative	8	6
27	1	Supported by a strong evolving business case	8	5
28	2	Cost	7.5	5
29	2	User Friendly	7.5	8.5
30	1	Efficient, resourceful, social conscience	7.5	6.5
31	2	Catalist for industry change	7.5	6
32	2	Time	7	2
33	1	Inspiring and challenging	7	10
34	2	Inspiring	7	10
35	2	about people	7	8.5
36	1	A sustainable project is one that considers the desires and requirements of all users	7	7
37	2	Educational	7	6
38	2	Open and Transparent	6.5	6
39	2	Modern	6.5	10
40	2	inclusive	6.5	8.5
41	2	Telling a story	6.5	6
42	1	Something that Endures, remains useful and well loved over time	6	3
43	2	Quirky	6	10
44	2	accessible to all	6	8.5
45	1	An asset, a positive relationship between form and function, inspiring	6	6.5
46	2	Using training within the project	6	6
47	1	Affordable in both build and operation	6	5
48	1	A shell that supports great ideas and projects	6	4

Ref.	Group	Consideration	Importance	Influence
49	1	Not a burden	6	2
50	3	Use of natural light - utilise light for even small back of house specific areas	5.5	1
51	2	Asking questions through the process	5.5	10
52	2	an inclusive project - accessible to all physically and emotionally	5.5	8.5
53	3	One whose physical construction has not reduced the earth's resources	5.5	8
54	2	One that tells lots of stories - what are the reasons for certain choices	5.5	6
55	3	Sits comfortablly within its setting... Becomes part of the landscape or compliments the place	5	5
56	3	"says" something about its location in design and construction i.e. The materials of the place	5	10
57	3	Learning from previous experience - good points from previous buildings and some not so good points	5	9.5
58	1	Something that has continuity and logevity	5	9
59	2	Communication	5	8
60	3	Intelligent, Monitors, Controls, Informs - status of resources impacted in daily use	5	8
61	3	Adapts to changing world	5	6
62	1	long term ownership	5	3
63	1	A celebration of the power that collective effort can achieve	5	2
64	1	Time (programme, resources)	4.5	1
65	2	A project that minimises environmental impact in all areas (visual / noise / habitat)	4.5	10
66	3	Minimal (zero?) carbon footprint in construction & operation	4.5	8
67	1	A place that people want to care for (Guinea pig not rat)	4.5	7
68	2	BREEAM (funding)	4.5	6
69	3	Location - transport	4	1
70	3	One that gives back as much energy as it consumes	4	8
71	3	A project that lasts	4	6
72	2	One that challenges the establishment (two fingers)	4	5
73	3	Makes the most of its location - access, passive energy, resources, connection to other assets	4	5
74	1	Funding requirements	4	4.5
75	2	Challenging (appropriate level)	3	2
76	1	A project that supports itself with the activities taking plae in and around it.	3	9
77	2	Using materials that have the same purpose of ordinary products but help reduce carbon emissions etc.	3	9
78	3	One that we will never want or need to demolish	3	6
79	1	Legistlation	3	4.5
80	1	A project that you want to be associated with	3	2
81	3	Physical footprint - limitations of size of site/location	2.5	1
82	3	Penalties for local materials?	2	3
83	3	Built out of intelligent bricks - every aspect thought through to minute details and justified	2	9.5
84	3	Flexible to material life cycles	2	8
85	2	Low Tech?	2	7
86	2	Pushing the boundaries of technology (flexible)	2	6
87	1	Skills Coordination	2	4.5
88	2	Natural materials	2	4
89	1	Understanding of use and purpose	1.5	2
90	2	Appropriate materials	1.5	9.5
91	2	Local materials and workforce	1	9
92	1	Preconceptions	1	9.5
93	1	Forward thinking	1	8
94	1	Gives more than it takes	1	7
95	1	The right design team	1	4.5

Figure 19: Importance vs. Influence Key

Summary & Key Points

'Collaboration & Inclusion' emerged as a key theme during the session typically being rated as highly important and with a high influence of the design team. Whilst collaboration and inclusion can be highly influenced by the design team during the design process, it is important to make clear that responsibility for this will lie with the building users after the handover of the process, and the design can only go a certain way to creating a collaborative and inclusive environment as this is emergent based on many complex interrelationships which include group culture and behaviour.

Issues which were primarily classed in the theme *'Pioneering, Inspiring & Challenging'*, were also typically regarded as both important and highly influenced by the design team. Whilst, this emerged as an important theme, the comments were generally very high level and non specific, such as, A sustainable building is; *'aw-inspiring'*, *'inspiring & challenging'*, *'a celebration of the collective of the power that collective effort can achieve'*. During the next phase of engagement it should be understood what actually represents these high level considerations and in which aspects the building should be pioneering, inspiring and challenging.

'Adaptable, Flexible & Future Proof', were also themes that emerged as primary considerations on many issues during the exercise. However, the main comments were again at a very high level, and questions should be asked as to what the intended usages are that require flexibility and what exactly are the design team future proofing for?

'Education and Outreach' also emerged as a strong theme and dialogue with stakeholders of the college including tutors, students and apprentices should be held as to what environment would enable them to teach/learn the best.

Aspects to do with *'Finance & Business'* case were typically classed as highly important but the influence of the design team in these considerations was generally consider less by the stakeholders. Responsibility for such issues should therefore not lie with members of the design team.

Themes relating to resources such as *'Energy'*, *'Materials'*, *'Water'* and *'Waste'* were not typically regularly occurring themes during this exercise. Again like the first exercise it should be clarified whether this is the case, or whether they were not mentioned significantly as they are considered aspects that are well covered by BREEAM and more standardised approaches. Interestingly during this exercise, the most commonly emerging themes were related to project specific considerations which were more focused on value (represented by pastel colours) than traditional environmental and social sustainability considerations (represented by the bright 'neon' colours).

Themes that were not well covered during the exercise include, as previously mentioned, resources such as *'Energy'*, *'Materials'*, *'Water'* and *'Waste'*. Additionally, *'Health, Comfort & Wellbeing', 'Heritage & Culture', 'Transport & Mobility'* and *'Maintenance & Management'*. Aspects relating to these themes should be discussed as part of the next workshop to ensure that these were not simply forgot or that they were not considered due to time restraints of the session.

Whilst it is understood that this categorisation into primary themes is not an exact science, it is hoped that this transparent approach through which each consideration can be tied back to the original post-it comment will provide an object around which issues can be discussed and prioritised for the project. Understanding the importance issues will help the design team to focus on areas which add both sustainability and value for the project.

4 Session 4: Relationship Mapping

Purpose & Structure

The purpose of this exercise was to map some interventions and relate these to sustainability issues they had identified as being important. Sustainability is complex and therefore the relationships and interdependencies need to be considered. This exercise was aimed at developing the groups' understanding collectively on the interrelationships for the building on these issues. The intended outputs of the exercise were relationship maps produced by the groups that resemble the map below.

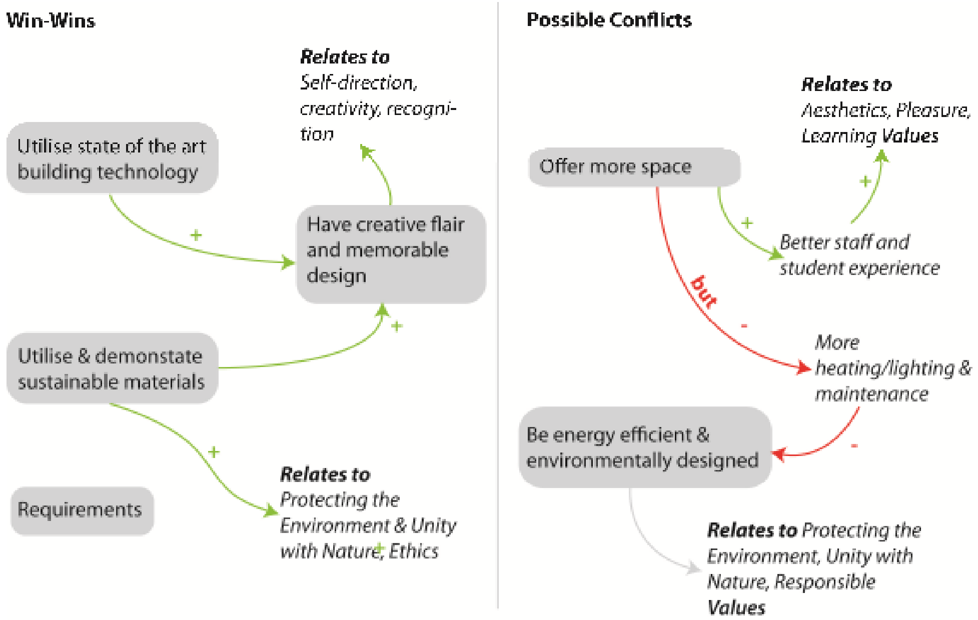


Figure 20 : Example of intended output of session

Output

The outputs of this session considered the interactions between issues and interventions. Whilst the output is interesting, the purpose of doing the exercise was to collectively think and develop a shared understanding of the inherent trade-offs between sustainability and value interventions amongst stakeholders. Therefore the primary purpose was to begin to build a collective understanding of the issues and relationships of selecting sustainable design options. In depth analysis of this exercise was not undertaken as it was not considered feasible at this stage, as there is not enough information to be able to assess whether the positive/negative relationship mapped were correct for the items considered. It is intended that a more comprehensive analysis will be undertaken at later stages of the development of the sustainability framework when design options are being considered in more depth by the design team.

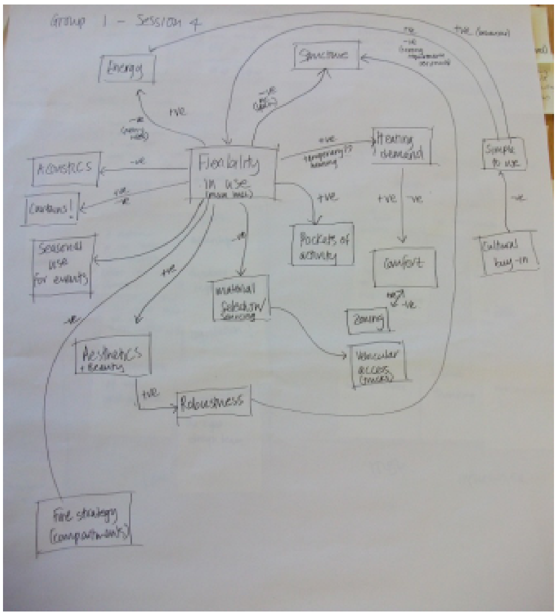


Figure 21 Group 1: Importance vs. Influence output (design team)

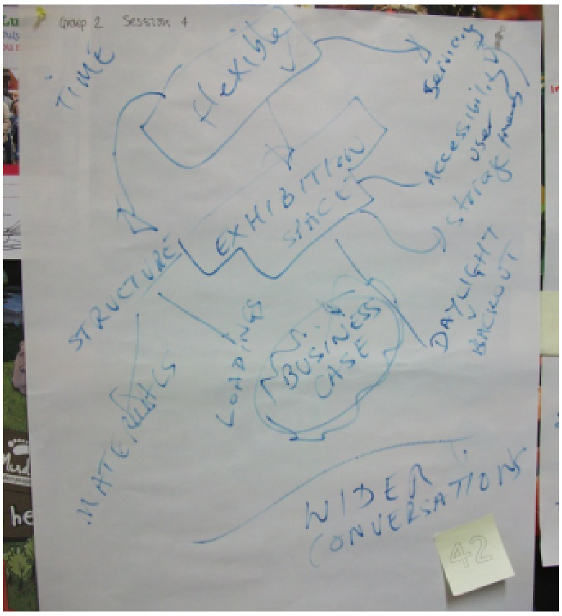


Figure 22: Group 2: Importance vs. Influence output (design team)

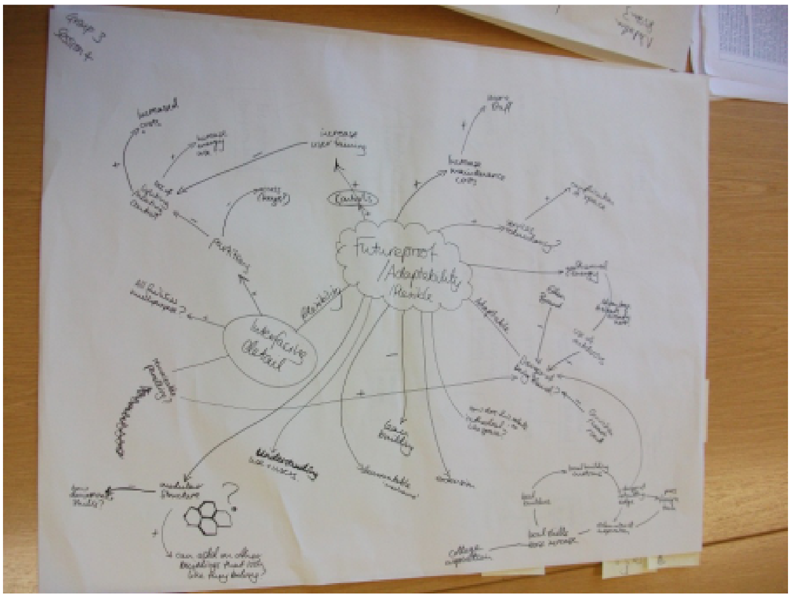


Figure 23: Group 3: Importance vs. Influence output (design team)

Analysis Method & Results

Figures 24 & 25 show the output of this session after items have been themed by the analysis team. This section discusses the key themes and relationships that emerged from the exercise. Red arrows represent negative relationships, whilst green lines represent positive relationships between the issues. Blue represents a relationship which wasn't shown as positive or negative by the workshop participants.

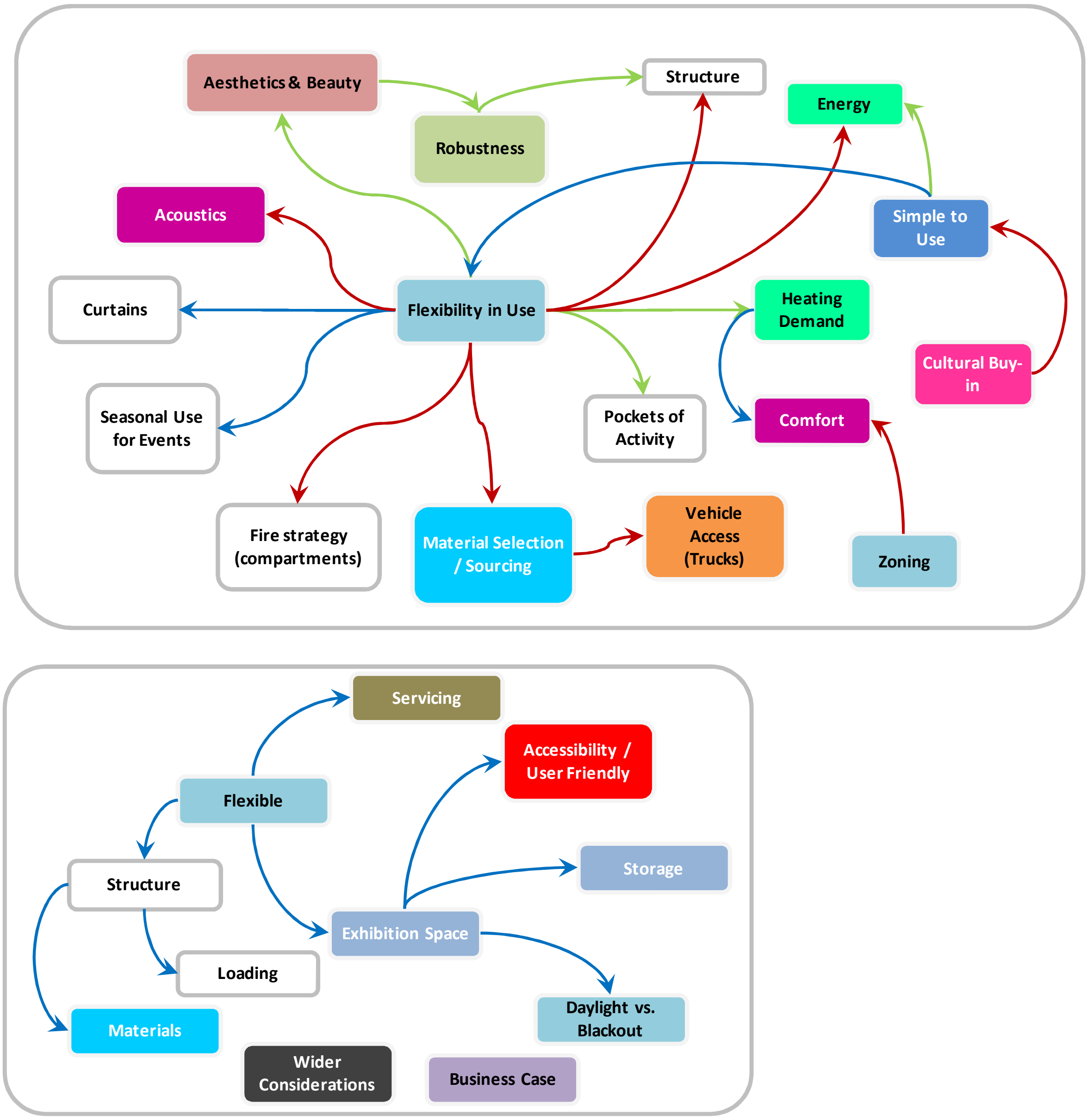


Figure 24 Output of Relationship Mapping Exercise (Top: Group 1. Middle: Group 2.)

Figure 25 Output of Relationship Mapping Exercise Group 3

Summary & Key Points

Flexibility/Adaptability was a main consideration, representing the central theme in two of the three diagrams. This demonstrates that achieving this requires consideration of many interrelated issues, some of which are positively connected and others which are negative. Understanding the 'win-win' and trade-offs is important and through such approaches these relationships are made more apparent and manageable.

Flexibility/Adaptability was seen to potentially make the building look bland by group 3 thus having a negative impact on the themes *'Love & Pride'.* However, a flexible and adaptable space was seen to have a positive impact on services redundancy, as the spaces would be better utilised. From a structural perspective group 1 considered that flexible spaces could potentially have a negative impact on the structure as through requiring larger spans to accommodate changes in room size. Group 1 also considered that flexibility would have to be closely considered with the fire strategy and the acoustics to ensure that it didn't have a negative and costly impact.

The diagrams provide a simple way of showing the relationships as understood by the stakeholder groups at the moment. Further thought should be given to other well discussed themes such as the desire for the project to be *'Pioneering, Inspiring & Challenging'* and the relationship between the 'Finance & Business Case' Considerations.

The relationships identified by the stakeholders, should be further discussed to assess whether the relationships (positive or negative) are correct and the strength of the relationships. Additionally the impact design interventions should also be considered.

5 Conclusions & Next Steps

On Tuesday 12th June a workshop was held between the stakeholders of the <project name> to understand in more depth what represented sustainability and value for the project. The 2hour workshop was split into 4 short sessions over which the stakeholders were asked to partake in several structured sessions. The aim was to discuss the important issues with respect to sustainability and value, develop a common knowledge and also capture the output of the workshop to use to guide further dialogue and discussion. The output for each session was captured and also analysed. Through this analysis key themes emerged and these themes were documented.

The session tended to suggest the need for a project specific sustainability framework as issues that emerged as important did not typically fit traditional environmental assessment systems such as BREEAM. Non standard issues that were identified from a social sustainability perspective included, *'Collaboration and inclusion', 'Education and outreach'*.

Additionally the following themes emerged as important from a value perspective and would not typically be grouped within a sustainability framework. These included the desire to have a pioneering, inspiring building that really challenged convention and was a 'catalyst' for change in the industry. Such issues were categorised under the theme *'Pioneering, Inspiring & Challenging'*. *'Adaptability, Flexibility & Future Proof'* also emerged as strongly represented theme from the issues identified during the sessions.

The next sessions included identifying opportunities and constraints for the project and exercise aimed at understanding the importance vs. influence of the issues identified. Again these were themed, mapped and a brief analysis is given within this document. From the opportunities and constraints exercise, time emerged as a major constraint of the project, however there were many opportunities identified for the project. These included utilising the knowledge Eden and acquired through other projects to help guide the design. Understanding was an interesting issue that emerged from the session, with the 'technical understanding' classed as an opportunity, but 'understanding' also identified as a constraint. Therefore further work should explore this. It is hypothesised that this might refer to a lack of understanding on what the project is aiming for at this stage. *'Adaptability, Flexibility and Future Proof'* again emerged as a theme and whilst it was seen that there was a real opportunity to develop an innovative and flexible building, it was highlighted that there is uncertainty under exactly what we are future proofing for. Again this demonstrates that there is less understanding on this issue and this should be addressed immediately.

The importance vs. influence exercise again was analysed afterwards and it is hoped will be used to guide future dialogue when prioritising what is important for the project. Interestingly during this exercise value related themes emerged more often than more typical environmental and social sustainability considerations. Issues with respect to energy, materials, water and waste were not considered as much as may have been expected. This should be explored as to the reasons for this. For example stakeholder may have not placed much emphasis on such issues as they may have thought the process of BREEAM would address such issues adequately.

Relationship mapping was conducted as the final exercise of the day in an attempt to understand some of the interrelationships between the considerations. Flexibility and adaptability was discussed and its relationships to other documents captured. The exercise was used to help stakeholders to understand potential win-wins and possible trades-offs between issues they considered important.

It is hoped that the workshop and the write up and analysis will clarify language and help guide future dialogue in the development a project specific sustainability and value framework. Additionally the themes identified and importance and influence exercise may provide a strong, stakeholder defined starting point to defining weightings for issues of importance.

Generally the output of all the exercises was at quite a high level and non-specific for this stage of design. The next session should begin to focus down on more specific aspects. For example whilst there was clearly a strong desire to have a flexible, adaptable and future proof building. These terms should be defined explicitly, and it should be explored what the daily flexibility requirements will be for the building and also what the long term adaptability considerations for such a building may be. This will allow the designers to utilise their skills to future proof in a way that is informed and define an appropriate level of flexibility and over a longer time frame adaptability.

Next steps should also seek to define how each of the important issues identified should be weighted, and assessed as the design progresses. It is believed that whilst some issues may be able to be quantified explicitly, such as energy, water and waste, more human or subjective considerations may not be able to be assessed thorough such means and more qualitative review sessions might be more appropriate. The process of defining and implementing the sustainability and value framework should be discussed as part of the next stakeholder session. This discussion should also include, who is responsible for various stages of the process and when actions are required.

Appendix K Case study 1C feedback

1 Case Study 1C Feedback

How successfully do you feel we have managed to capture and discuss the sustainability perspective of your group in today's workshop? 0 (Not at all) – 10 (Completely)

Average = **6.6/10** (5 responses)

Difficult to define sustainability when the building's use hasn't yet been defined

Please make sure the report with key priorities are shared promptly

Think we lost our way a little in the middle two session - we were still thinking at a very high level

Lots of ideas

I felt comfortable to share my view and opinions. 0 (Not Comfortable) – 10 (Very Comfortable)

Average = ***9.2/10*** (5 responses)

How efficient and effective do you feel the workshop has been?

Well timed and facilitated

Quite useful - looking forward to next level of detail

First session was best in providing new ideas and seeing commonality of thought, Last session led to very useful and interesting discussion and some specific ideas

It will be interesting to see the report

very useful

Which parts did you find least interesting/irrelevant?

Importance vs. Influence

Session 4 [Group Model Building]

Hardest was deciding the influence / importance levels of our ideas - all seemed very important!

All very interesting

All aspects

Have you got any suggestions on how we can improve the engagement session?

Provide stakeholders with more understanding of project prior to next session

Start by explaining premise and stages of project with a timeline and outline of what can be influenced now

We felt we needed to understand the brief better for the buildings use - we could then have been more specific in our contributions

A bit longer to discuss

No

Please leave any other thoughts, opinions or specific questions regarding anything discussing in the session below (if you have specific questions please leave your email address so we can get back to you).

Would have liked to have seen other groups output at end of each workshop but appreciate that this would have been time consuming

Good luck drawing it all together

Appendix L Green roof literature review

This appendix provides additional coverage of the green roof literature and provides a more detailed review of green roof systems which are summarised in the literature review in Section 3.6.2.

Sustainable Drainage

There are a wide range of research papers that are concerned with the impact of green roofs with respect to sustainable drainage. These can be classified into three areas (Green Roof Organisation, 2011):

- **Retention of water,** through storage in the growing medium and evapotranspiration from the roof's plants and substrate, reduces and slows runoff volumes, reducing the burden on the sewer network and lowering water treatment costs.
- **Detention of water,** due to the time for water to infiltrate and permeate the substrate, reduces peak rates of runoff, helping to reduce the risk of flooding.
- **Water quality** improvements through the filtration of pollutants during the process of water infiltration.

Research in these areas is discussed in the follow subsections.

Retention of water

Environmental advantages of green roofs are generally accepted across the literature to include a decrease in surface water runoff volume. Green roofs provide a natural living surface and in doing so mimic the runoff characteristics of the natural environment to some extent (Figure 1).

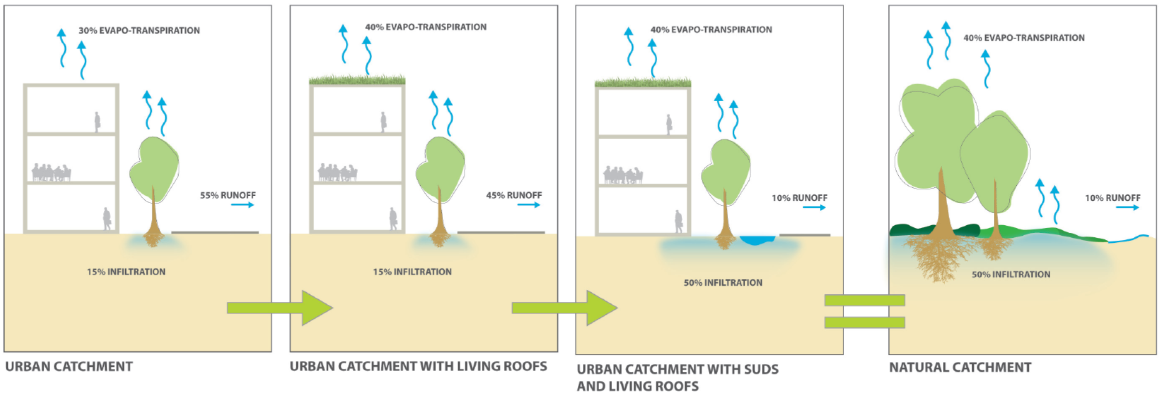


Figure 1: Mimicking the natural catchment with green roofs as part of a SUDS strategy. Buro Happold Design Note, Phil Hampshire (2009) modified from Grant (2006b).

Factors affecting the reduction in runoff include, Green roof type (Depth of substrate, plant type), geometrical properties (roof slope), climate (season, rain fall, humidity), Soil Moisture characteristics (i.e. how wet the soil is prior to rainfall events), age of green roof (how well established the green roof is (Getter et al., 2007, Czemiel Berndtsson, 2010).

The reduction of runoff has been quantified by several authors on a variety of scales and under many rainfall situations. However, the most commonly quoted annual average retention rates are from the FLL (FLL, 2002). The deeper the substrate, the more water the roof can hold and the greater the reduction in runoff. Table 1 demonstrates some of the commonly used water retention figures. It should be noted that whilst these figures are typically used as rules of thumb estimates, they relate to locations with annual precipitation values of between 650 – 800mm per year. In regions with lower annual precipitation values, water retention is higher and vice versa. Figure 2 shows data from 31 rainfall events and shows the % retention against the depth of rainfall. This data is taken from (Carter and Rasmussen, 2006). This demonstrates that with larger rainfall events the percentage retention reduces significantly.

Table 1 Reference values showing percentage annual water retention on green-roof sites in dependence on course depth (FLL, 2002)

Type of greening	Course depth (cm)	Form of vegetation	Water retention - annual average in %	Annual coefficient of discharge / sealing coefficient
Extensive greening	2-4	Moss-Sedum	40	0.60
	4-6	Sedum-moss greening	45	0.55
	6-10	Sedum-moss-herbaceous plants	50	0.50
	10-15	Sedum-herbaceous-grass plants	55	0.45
	15-20	Grass-herbaceous plants	60	0.40
Intensive greening	15-25	Lawn, shrubs, coppices	60	0.40
	25-50	Lawn, shrubs, coppices	70	0.30
	>50	Lawn, shrubs, coppices, trees	>90	0.10

Mentens, Raes et al. (2006) showed that the potential regional runoff reduction by greening 10% of buildings in the Brussels area with extensive green roofs of substrate layer depth equal to 100mm to be 2.7% for the region and of 54% for individual buildings. Other figures suggest that runoff in some situations can be reduced by 100% (Wolf and Lundholm, 2008). Whilst runoff retention figures vary across the literature, studies by Getter, Rowe et al. (2007) show that this variation can be attributed to the effect of roof slope, the amount of precipitation, different rainfall patterns at different locations, and the saturation and depth of the substrate. They also suggest that the establishment period of the green roof may also affect the percentage of runoff reduction, as greater maturity may increase the hydrological conductivity of the substrate. Their experiments with roofs of slopes ranging between 2% and 25% and varying rainfall intensities showed an average retention of 85.6%.

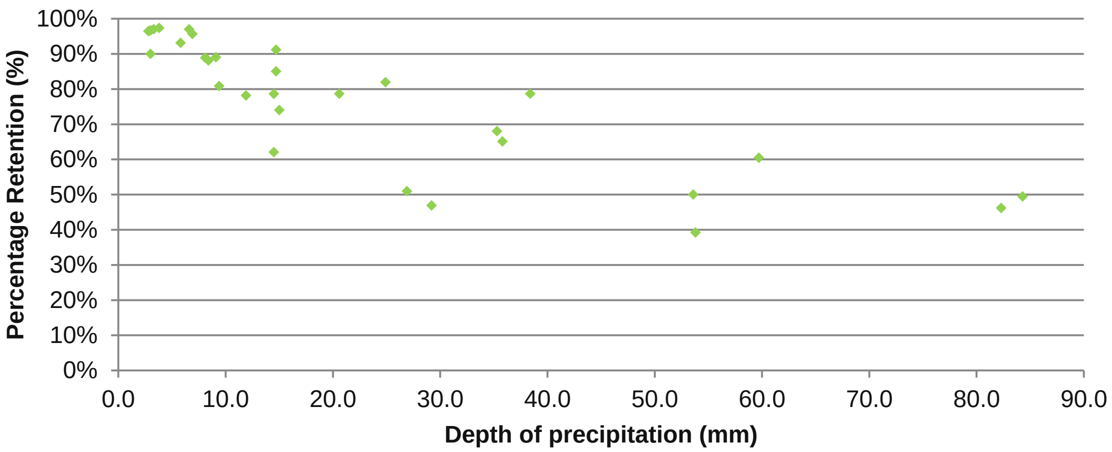


Figure 2 Percentage retention for a green roof for 31 rainfall events after (Carter and Rasmussen, 2006)

A meta-analysis of the retention data has recently been conducted by (Gregoire and Clausen, 2011). This is combined with (Czemiel Berndtsson, 2010) to provide the retention figures shown in Table 2. However, what is missing from this information is the context of the information. For example, roof build up and climate type. This is included in (Mentens et al., 2006) who review a number of papers not published in English (mostly German) across a range of roof types and also include the annual rainfall at the place of study, along with the intensities of rainfall where available, substrate depth and location. This includes extensive, intensive, gravel and traditional roof types. From the data and simple regression analysis, equations were developed that could be utilised to predict the annual retention, based on the depth of precipitation and the substrate depth of the green roof. These had significant coefficient of determination (R^2) value of 0.99. Additionally, different equations were proposed for summer and winter runoff, which is also useful information. The data however, only is of use for the rainfall range of 554-1347mm and a substrate depth from 30-380mm.

Table 2 Average retention rates from several studies.

Reference	**Year**	**Rainfall retained in green roofs, average during study period**
Gregoire, B.G et al.	2011	52%
Bengtsson et al.	2005	46%
Berghage et al.	2009	53%
Carter and Rasmussen	2006	61%
DeNardo et al.	2005	45%
Hathaway et al.	2008	64%
Hathaway et al.	2008	63%
Hutchinson et al.	2003	68%
MacMillian	2004	54%
Monterusso et al.	2004	49%
Steusloff	1998	68%
Stovin	2010	34%
VanWoert et al.	2005	61%
Moran et al.	2005	63%
		55%
Monterusso et al.	2004	49%
Average		55.2%

Computational modelling has also been undertaken, utilising a simulation package called Hydrus 1D, to estimate the impact on detention and annual retention (Hilten et al., 2008). However, this is a somewhat more involved process when compared to (Mentens et al., 2006).

Quantitative assessment:

It is proposed that the equations based on regression of data from over 125 green roofs are utilised for the Western and Central European region and regions with similar climate types (Mentens et al., 2006). Alternatively, the best data available can be looked up based on roof type (substrate depth, climate type and annual rainfall) utilising the approach developed to utilise existing research in Section 12 of the main body of the thesis.

Detention of water and reduction of peak runoff

Green roofs can reduce peak runoff flow and accomplish this reduction in surface water volume and peak discharge by “delaying the initial time of runoff due to the absorption of water in the green roof system; reducing the total runoff by retaining part of the rainfall; and distributing the runoff over a long time period through a relative slow release of the excess water that is temporary stored in the pores of the substrate” (Mentens et al., 2006). This is demonstrated in Figure 3

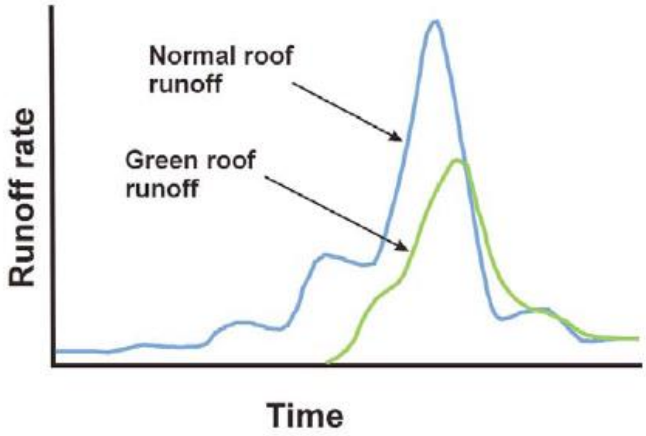


Figure 3 Example comparison of runoff from green and conventional roofs (Newton, Gedge et al. 2007)

The peak flow reduction performance of green roofs is categorised as medium in the Sustainable Urban Drainage Systems (SUDS) manual (CIRIA, 2007). However, the manual also states that there is a need to discharge excess water to the buildings drainage system. Additionally, it states that the performance of green roofs during extreme events tends to be similar to standards roofs, so the hydrological design of the roof should follow the same guidance as for a standard roof. This requires the designer to follow EN BS 12056-3:2000 (British Standard, 2000). However, in the FLL (FLL, 2002), runoff coefficients are modified for the type of green roof, but the CIRIA guidance does not allow this. Thus under the German code, green roofs are accepted to reduce peak runoff; however, in the British version this is not allowed.

Many studies have looked into the ability of green roofs to detain peak runoff flows. (Carter and Rasmussen, 2006) tested green roofs for 31 rainfall events and showed that peak flows were reduced in all but one occasion. This utilised a 7.6cm depth roof, which falls into the extensive category of green roofs. This was planted with Sedums. As can be seen for all but one rainfall event, the peak runoff rates were reduced. The average reduction of peak runoff flows was 55%.

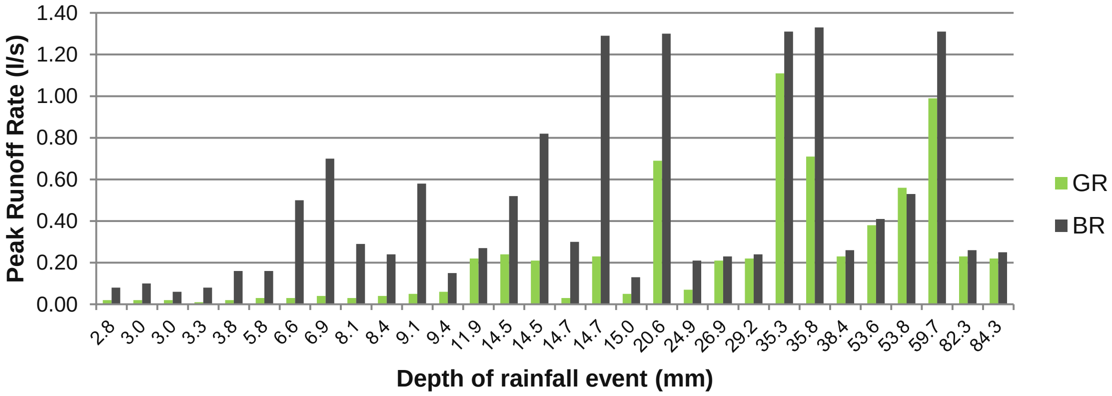


Figure 4 Peak Runoff Rates (l/s) for 31 rainfall events. Green roofs (GR) compared to Traditional Black roof (BR)

Additionally, their study also investigated the delay from peak runoff by green roofs. The figure below shows this information for the rainfall events. This shows only two occurrences where the green roof runoff peak was quicker than the conventional roof. The average delay when compared with a conventional roof was approximately eight-teen minutes.

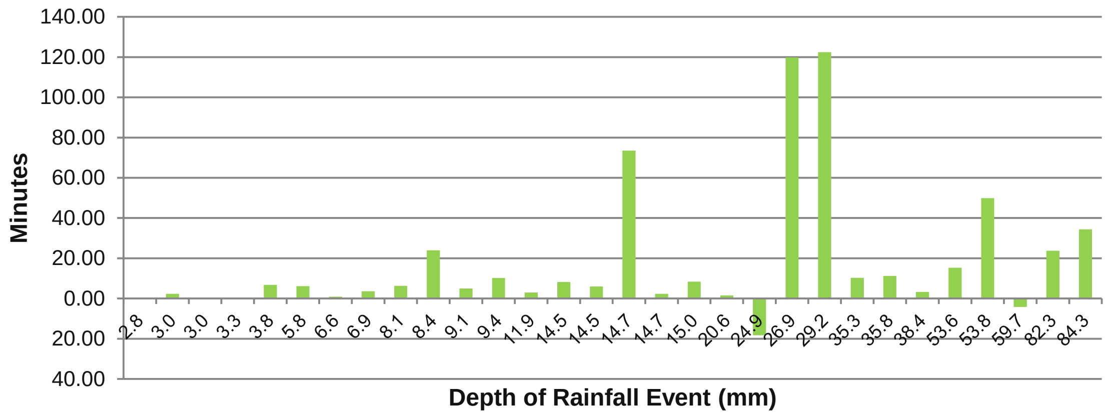


Figure 5 Delay in peak runoff by green roof compared to black roof

Quantification: Modelling undertaken by (Hilten et al., 2008) used a one dimensional model to assess the storm water performance of a 100mm extensive green roof. Their results were verified for site data. The model accurately predicted runoff for small rain events, however for larger events the model over predicted retention. The model showed 100% retention for storms less than 20mm, and provided detention for storms as large as 80mm. Their model allows weather data for any location to be input to determine runoff for any depth soil media. However, the model has not been verified with any other green roofs data. The study shows that the rainfall depth for the storm strongly influences the performance of green roofs for storm water mitigation. Detention was also seen for larger storms assuming the measured average moisture content of around 10% as the antecedent condition.

Runoff quality

The pollutant removal by green roofs is often expected, however it is commonly not a design feature (Berndtsson et al., 2008). The water quality treatment performance of green roofs is classified as good according to the CIRIA SUDS Manual (CIRIA, 2007). However, research findings tend to vary on the performance of green roofs to improve runoff quality. This section builds upon a recent review paper on this subject area (Czemiel Berndtsson, 2010).

Aspects that are generally considered in runoff quality are concentrations of phosphorus, nitrogen, heavy metals and pH (Czemiel Berndtsson, 2010). Although papers do often consider more aspects of water quality. A summary of the aspects considered in runoff water quality of different authors is shown below.

Berndtsson et al. (2006) looked at the influence of extensive roofs on runoff water quality. Their study included considering the runoff of four full scale installations in Southern Sweden and comparing runoff quality with non-vegetated roofs in the study areas. Their study aimed to understand whether green roofs were a source of contaminants or a sink. Green roofs were shown to be a source of contaminants for all but nitrogen.

A recent study by Mendez et al. (2011) looked into the quality of runoff from several different roof types, for assessing the feasibility of different rainwater harvesting systems. They concluded that roof choice was an important consideration when designing a rainwater catchment. Whilst metal roofs are often chosen for their water quality runoff, concrete and cool roofs performed similarly and produced harvested rainwater quality similar to that from the metal roofs. Additionally, whilst shingle and green roofs performed similarly to metal and concrete roofs in many respects, the study showed higher dissolved organic carbon concentrations (in some cases these differences were as large as one order of magnitude).

Carter and Jackson (2007) also express another advantage due to the retention of rain water at roof level; this is that pollutants are not washed off impervious surfaces into the drainage systems. The benefit of which is there is no treatment and re-release on this volume of water, as the water cycle is effectively short circuited at the roof level.

(Beck et al., 2011) have looked into the content of green roofs, and amended green roof soil with biochar to see the impact it has on water quality runoff. Whilst the exact build up and selection of materials in green roofs is beyond the scope of this research, the findings were interesting with improvements in water retention of 4.4% when compared to other green roofs at near saturation. Additionally, their results showed improvements in the water quality of runoff. Biochar-amended soil showed a 67-72% reduction of total organic carbon in the rainfall runoff for both soil-only and plant trays. Improvements included, decrease of nitrate, total nitrogen, phosphorus, total phosphorus and organic carbon concentrations entering into the rainfall runoff. Unfortunately, all the tests were conducted on different types of green roofs, in a laboratory setup, so no comparison is available with other roof types.

Quantification of performance: As the quality of runoff varies significantly, based upon the type of green roof, it is proposed that quality estimates are undertaken on a case by case basis and looked up for a specific type of green roof. Results are too fragmented and variable at present to be able to model this performance quantitatively based on equations and parameters. Therefore any input with respect to water quality should be considered on a case by case basis with respect to decision making.

Thermal performance

Papers referring to the thermal performance of green roofs tend to fall into two categories. These include (1) the impact of green roofs on the building's heating and cooling loads, and (2) the impact of the green roofs on the urban heat island effect. In both cases the thermal processes and interactions that occur on a green roof are complicated, with all forms of heat transfer typically taking place. These include changes in both sensible and latent heat exchanges. The advanced thermal interactions on-going in green roofs are a research area in their own right and the current state of the art is summarised here under the two category headings as mentioned above.

Building Heating and Cooling Loads

Green roofs have the ability to reduce both heating and cooling loads in buildings. This has positive implications in terms of their energy consumption. They achieve energy reductions by reducing the thermal fluctuation of the outer surface of the roof and by increasing the roof's thermal capacity (Niachou et al., 2001). Other ways in which plants keep buildings warm is that foliage protects the building from winds. The process of heat transfer into green vegetated roofs is very different to those of conventional roof surfaces. In green roofs, solar radiation, external temperature and relative humidity are reduced as they pass through the vegetation layer. The plants also provide cooling by their biological processes such as evapotranspiration, which converts large amounts of solar radiation into latent heat, which does not cause the temperature to rise (Takakura et al., 2000). The remaining solar radiation is changed into thermal load, which can pass through the roof and thus influence the internal climate of the building (Niachou et al., 2001, Spala et al., 2008). Temperatures on a black flat roof can reach up to 100°C (Ramachandran et al., 2002, Wong et al., 2003b). The addition of a green roof vastly reduces the temperature fluctuations to around 20 to 25°C (Wong et al., 2003b).

The majority of papers written on the cooling effect of green roofs agree that the main parameter that effects the heat transfer through the roof is the leaf area index (LAI) (Barrio, 1998, Takakura et al., 2000, Theodosiou, 2003, Kumar and Kaushik, 2005, Sailor, 2008). LAI can be defined as the upper surface leaf area per unit area of base (which in this case is the roof). It is dimensionless (m2/m2), and usually for plants has a range from 0.5 to 5 (Sailor, 2008). It is also worth noting that the LAI is often directly related to the amount of evapotranspiration of the plants, the greater the LAI, the bigger the total leaf area is (where transpiration occurs). In addition, large values of LAI offer practically complete shading to the soil layer, protecting the roof from solar irradiation (Theodosiou, 2003). There are also other factors that Sailor (2008) notes that effect heat transfer through the roof, which include height, fractional coverage, albedo, and stomatal resistance. It is worth noting that excluding albedo, all other factors noted here affect the degree of evapotranspiration and shading of the roof, whilst the albedo affects the radiative heat transfer through the roof.

Barrio (1998), proposed a mathematical model to represent the dynamic thermal behaviour of real green roofs, and to analyse their potential as cooling devices in summer time. Her analyses show that green roofs do not act as cooling devices but as insulation ones, reducing the heat flux through the roof and thus reducing heat gains. This is contradicted by more recent research (Theodosiou, 2003, Kumar and Kaushik, 2005) who find in their modelling that green roofs do indeed providing cooling potential. Their model is compared to a real world green roof building and is found to be very accurate with an error range of +/- 3.3% in predicting green canopy-air temperature and +/- 6.1% in indoor air temperature.

Takakura, Kitade et al. (2000) also examine the cooling effect of greenery cover on a building, both using computer simulations, and by actual real world models. They detail their experiment in which they use 0.9m x 0.9m boxes to compare the cooling effect of different types of greenery. The paper concludes that “surface conditions, especially through the LAI factor and the amount of evapotranspiration from the top surface, have a large effect on the heat flow into the air space beneath.” The simulation model that was developed also agreed fairly well with the measured results. Although there are limitations with their methods, such as scale effects that would occur when scaling up the small 0.9m x 0.9m boxes to those of a real size building, it is thought that there methodology is well considered and that there is real scope for expanding their work. Benefits of their approach are that; it easy to implement; it does not use large amounts of space; it is reasonably cheap; and it offers excellent comparison between different roof surfaces, as there is no differences in operation of the internal space that would affect the results.

One should be aware that whilst green roofs offer savings in the cooling load of buildings and can also reduce winter heating load they can in some situations increase winter heating loads. For example, Sailor (2008) found that increasing the thickness of the soil layer resulted in reduced demand for both heating and cooling, with larger heating savings in a cooler climate, but increased LAI, increased the amount of winter heating required due to increased shading effects that are beneficial in summer but detrimental in winter. A year round analysis should ideally be taken to optimise the green roof for maximum benefit throughout the yearly climate cycle. Many papers analyse green roofs through a short time period, say the cooling potential in the summer, or reduced heat energy savings in the winter through increased insulation, but few studies have looked into optimising the green roofs for performance through an annual cycle.

Quantification: Sailor (2008) has created a model for the evaluation of the impact of green roofs on the energy consumption of buildings. This has been developed to work with the EnergyPlus building simulation programme. This is the most advanced model of green roof thermal performance and accounts for all types of energy exchange. The model has been tested and validated on green roof performance in Florida. The source code for the program is also available, meaning that modification of the code to provide suitable outputs is also available. This is the method used to model the performance of green roofs in relation to the building heating and cooling loads.

Urban Heat Island Effect

It is widely accepted across the literature that green roofs have the ability to reduce the urban heat island (UHI) effect. The UHI effect is summarised in more detail in section 4.3. The extent to which green roofs can reduce the temperature of their surroundings and thus mitigate the UHI effect is based on climatic characteristics, the amount of vegetation and urban geometry (Alexandri and Jones, 2008). Vegetation reduces the UHI effect due to changing the albedos of urban surfaces and evapotranspiration cooling. They also provide some shading of the roof due to the plants canopy area and thus reduce the temperature of the roof. Evapotranspiration from trees can produce an “oasis effect” where urban ambient temperatures are significantly lowered. Green roofs are essentially vegetated roofs with species ranging in size from sedum on extensive green roofs to shrubs and trees on intensive green roofs. They consequently exhibit the cooling effects described above. Alexandri and Jones (2008) developed a computer model to quantify the potential reduction in temperatures in numerous cities of different climates around the world. They conclude that for hot, arid climates, such as Riyadh, air temperatures at roof level can be reduced by an average of 12.8°C, whilst canyon temperatures can be reduced by a temperature of 9.1°C. It should be noted that these results were obtained for the average hottest day of the year. Whilst their results were good at showing the general cooling effects of vegetation in cities, there are large limitations of their methods and model. Their model assumed that all horizontal and vertical building surfaces (walls and roofs) would be covered with vegetation, something that in reality would be unfeasible. Also, whilst the model mathematically considered the heat and mass transfers in a typical urban canyon in considerable depth, the model was two-dimensional and based on assumptions of varying canyon widths and heights that are unlikely to closely resemble those of the actual studied cities. Whilst their results are useful for showing general trends, such as where placing vegetation has the maximum effect in UHI mitigation, the actual numerical values should be considered with caution.

The reduction of the UHI effect with green roofs is hard to predict accurately at present. This is due to a vast number of variables involved; each city has a different climate, geometries, land uses, building types, all of which have large uncertainties in their values without extensive research. However, it is clear from the literature that green roofs offer a large scope for vastly reducing the UHI effect. With reduced city centre temperatures follows the benefits of reduced cooling energy requirements in cities, improved air quality and a reduction in CO_2¬ emissions of power plants (Akbari, 2002). This shows that improvements are made on the economic, social and environmental fronts and thus marked sustainability improvements can be recognised through green roofs.

Quantification: Some authors have looked at establishing proxy metrics for assessing UHI effect. Scherba et al. (2011) has utilised a model for calculating the thermal performance and energy saving benefits of green roofs and also calculate the sensible thermal flux into the built environment. This was used to assess the performance of various roof systems and the benefits of green roofs. Interestingly, the paper also considered the implications of adding solar panels to the various roof systems and the implications from an UHI perspective. It should be noted that whilst the paper provides an excellent indication of the performance of different roof types on the impact of urban heat island mitigation efforts, it does not represent the direct impact on urban heat island effect, which is dependent upon a multitude of other variables.

Planting type and dynamic plant performance

Numerous papers have explored the performance of different plants and substrate types on the dynamics and annual changes of the green roof systems for different climates. This includes a review for the North American region by Dvorak and Volder (2010), which considers the difference in plant survival across different roof types. Additionally, conclusions include that diverse roofs tend to perform better. This is also supported by (Nagase and Dunnett, 2010), who looked at different planting regimes across three major plant groups including forbes, sedums and grasses and different watering conditions. Drought tolerance was shown to be best amongst sedum groups, but greater diversity of functional plant types gave rise to greater survivability (as they were not competing for the same resources) and also higher visual ratings.

Studies have also been conducted in the UK looking at the impacts of substrate depth and planting types on the survival rates, density and percentage coverage over six growing seasons (Dunnett et al., 2008). The conclusions of this study were that the best plant performance was achieved at 200mm substrate depth (the deeper of the two tested) and that there was significant changes across the 6 growing seasons indicating a greater need for extended and monitored long term research. Other studies have looked at the impact of age on green roofs and biodiversity levels (Schrader and Böning, 2006) and the impact on soil nutrient levels. Soil conditions were shown to be more stable on older roofs but species richness did not vary significantly.

Additional studies have looked at plant density, height and floristic composition in Sweden across seven green roofs, which included three plant groups; trees and shrubs, common ruderals, and species associated with marshlands (Archibold and Wagner, 2007). Additional studies undertaken in Sweden also looked at the impact of establishment method on low weight extensive systems of less than $50kg/m^2$ saturated weight (Emilsson, 2008). This showed a lack of difference between the establishment methods demonstrating that other more cost effective establishment techniques may be possible.

(Molineux et al., 2009) have also studied the impact of soil type on the performance of green roofs. This includes studies looking at the viability of different recycled waste materials in comparison to crushed red brick, which is the UK standard aggregate type. They conclude that recycled materials, which include clay and sewage sludge, paper ash and carbonated limestone, could be commercially viable options with great potential in the green roof market. They perform potentially better than the industry standard from an environmental and economic perspective and have the advantage that they can potentially be locally sourced. They also confirmed that leaching levels were within safe limits. Other studies have looked into the impact of soil type on the plant performance of green roofs. This includes a study by (Rowe et al., 2006), who looked into varying the percentages of heat expanded slate and the fertiliser rates on the survival rates of various plant types. They concluded that it is possible to reduce the amount of organic content in green roof substrate if minimal levels of fertiliser are applied whilst still maintaining plant health. The benefits of which are that discharge of nitrogen, phosphorate and other contaminants is reduced considerably. Other studies have even looked at the feasibility of using rubber crumbs to substitute the porous stone materials, usually used to make up the growing substrate (Vila et al., 2012). They conclude that early results show that rubber crumbs are a good substitute. The benefits of which means that it would provide a solution to the problem of waste tyres.

Quantitative assessment: The above papers provide good evidence of the impact of soil selection, plant type and changing the growing substrate. However, all look at specific combinations of variables on the impact of plant performance, diversity, survivability, and visual appearance. The number of variables that influence the proceeding things is large and includes plant types, soil types, nutrient mixes, substrate materials and will also be dependent on local climatic variables. The sheer complexity prevents this from something which is easy to model and with each project location having a different set of native species, it is considered outside the scope of this research to provide a decision support system as to the best plant types for use. It will be assumed that appropriate plant types will be selected for the green roof by a suitably qualified professional.

Suggested future steps for this work could be to start creating a different palette of plant options and soil types for different climate types. Such 'palettes' of options have been created for Hong Kong, which commissioned a study into the suitability of different plant types for their region. Plants suitable for extensive roofs are categorised under the following fields; minimum soil depth; Maintenance (high / medium / low); Wind Tolerance (high / medium / low); Pollution Tolerance (high / medium / low); Growth Rate (high / medium / low); Conspicuous Flowers (yes/no); Interesting Foliage (yes/no); Used in Hong Kong (yes/no); Additional Notes (Urbis Ltd., 2007). There is also information on the following fields for intensive green roof plant types, which include the size to which the intensive plants will grow (medium / large); whether it is evergreen or deciduous; and whether the foliage is interesting, conspicuous or fragrant.

Local Biodiversity

Green roofs can provide green islands that if well planned, can cater for a variety of flora and fauna unattainable on traditional roofs. There are examples where green roofs have created a habitat for some endangered species, for example the redstart in the London area (Newton et al., 2007). They can also provide islands and corridors for wildlife in areas of limited biodiversity such as towns and cities. Green roofs may function as 'stepping stone' habitats, connecting isolated habitat pockets with each other to promote urban biodiversity (Schrader and Böning, 2006). There is a small but growing body of evidence that demonstrates the biodiversity value of extensive green roofs in the UK (Grant, 2006a) and in Germany (Kohler, 2006). A summary of a significant amount of this research can be found in (Newton et al., 2007). This includes a study of the green roof at the Moos Lake Filtration Plant in Switzerland, which contained over 175 different types of plant species, many of which were classified as rare or endangered in the local region. On the basis of their plant diversity, the roofs are now classified as a national park and contain some species which are not found elsewhere. The build-up of this roof is classed as semi-intensive, with a drainage layer consisting of 50mm sand and 150-200mm of top soil, which was allowed to colonise naturally.

Other studies have looked at the changing biodiversity of extensive green roofs (Kohler, 2006, Köhler and Poll, 2010). In Kohler (2006), he studied the changes in biodiversity over time across numerous extensive green roofs of substrate depth of approximately 100mm across two different sites in Berlin. The first included ten extensive green roofs with a total area of around 650m^2. The second site consisted of three extensive green roofs with a total area of 2000m^2. Both were assessed regularly over a twenty year period through measuring the number of vascular plants (species richness), percentage coverage of plant species, plant heights and the percentage of plants with dead leaves and stems. For site one, the number of plant species ranged from 8 (when the weather was very dry) to 25 with an average number of species observed being 15. On the second site the minimum number of species observed was 22 and the maximum was 64 with an average of 40.

A study of different types of extensive green roofs with different establishment periods showed that about 70 different plant species were consistently found on extensive green roofs (Köhler and Poll 2010), although 100 were identified across the green roofs studied in Berlin. Another study conducted (Kohler et al., 2002) looks into the impact on the biodiversity / species richness of installing photovoltaics on an extensive 10cm depth substrate green roof in Berlin. This showed that after installation of PV panels the average cover (%) increased and the number of species also increased from 41 to 43. Additionally, the cover of sedums decreased from 48% to 27% as they no longer became dominant due to the greater variety of plant species. The number of species that was found to benefit from the panels was 7 and the average height of the plant species also increased significantly. Their study also mentioned how, due to reduced surface temperatures of the roofs in comparison to traditional 'black' roofs, there may also be improved efficiencies of the PV system, as PV works more efficiently when it is cool. This demonstrates the synergistic effects of the system types.

Manufacturers now offer different systems with species richness already defined. For example, Bauder offers a wildflower green roof blanket with 24 UK native plant species (Bauder, 2012). Sedum Blankets are also available, which are planted with 11 UK native species. Additionally, roofs can be plug planted to achieve a greater degree of biodiversity and a higher species number. Guides are available that outline a range of natives species for the UK along with the suitable exposure conditions (shaded/unshaded), the colour of the flower, if appropriate, and the expected height of the flowers (Bauder, 2013b). Other manufacturers also provide such information (Alumasc, 2010).

Quantitative Assessment: There are many different ways of quantifying biodiversity, which include counting the number of species present on roofs. However, for the purposes of this research, the biodiversity of different roof options will be quantified utilising the same method as proposed in BREEAM (BRE, 2011) (p209), this assesses the species richness (also known as the average total taxon) and takes an area weighted average of the plant species richness as an indicative measure of the ecological value of the site. The same approach will be applied here to the roof area.

Durability and Lifespan

Other more tangible economic, social and environmental benefits come from the decreased maintenance and replacement cost savings of green roofs. This is due to the reduced temperature fluctuations and the protection of the water proof membrane from ultraviolet (UV) radiation. The result is a prolonged lifespan, which Wong et al (2003a) agues can be a minimum of threefold if installed correctly. However, more typically quoted figures are more conservative stating life extensions of the waterproofing membrane of 200% (Carter and Keeler, 2008). A longer service life of roof systems means that maintenance and replacement are less frequent and thus costs are reduced. Other authors have tried to quantify the performance of green roofs on durability and life span including (Bjork, 2004) who utilised modelling to predict the extension of service life. The study considers the temperature of exposed and green roof membranes and assumes that the largest degradation occurs at the highest temperatures and their preliminary results suggest that under certain presuppositions, it becomes possible to estimate service life extension. They show results that suggest that in the case of a referenced service life of 40 years, an exposed roof will have an estimated service life of 26.9 to 35.9 years with a green roof covered membrane having a service life of between 38.9 and 39.4 years thus demonstrating service life extensions of between 10% and 30%. However, their study also states that further experimental work is needed. The results do not tend to agree with the more optimistic results that are stated by (Carter and Keeler, 2008, Wong et al., 2003b). There are current examples of green roofs and their potential to extend roof lifespan, which include that of the 30,000m^2 green roof laid on a mastic asphalt waterproofing on the Moos Lake Filtration Plant in Switzerland. This is currently 100 years old (Newton et al., 2007). The typical life span of mastic asphalt if correctly laid is between 50-60 years (Harrison et al., 2009). The current roof has had very little maintenance and demonstrates the impact that green roofs can have on extending the design life of roof waterproofing. Other studies have also stated that green roofs if properly laid can last up to 100 years (Köhler and Poll, 2010).

Quantitative assessment: Research demonstrates that life span varies significantly across authors and that techniques aimed at modelling the impact of extension to service life are not yet robust. Therefore, for the purposes of quantification for the decision support tool, no modelling will be undertaken that reflects the impact of the local context specific climate. Instead, it will be assumed that the addition of a green roof extends service life by approximately 100% on the warrantee period of the membrane, which agrees with many research studies.

Air quality

Air pollution removal is another environmental advantage of green roofs. Air pollutants are removed by the high surface area and roughness provided by the branches, twigs, and foliage of plants. As vegetation reduces the urban temperatures photochemical reactions are slowed down and this leads to less secondary air pollutants, such as ozone. (Yang et al., 2008). Yang et al (2008) attempted to quantify the air pollution removal of green roofs in Chicago by using a dry leave deposition model. Their results show that current green roofs in Chicago annually remove 1675kg of pollutants, with the potential to remove 2046.89 metric tonnes if all roof tops were greened. However, the cost of doing this is likely to be prohibitive at $35.2 billion for relatively small pollutant savings. The quantities of air pollutants removed by green roofs are not well documented in the literature so validation of these results is difficult. However, there is literature on the air pollution removal of general urban vegetation, which shows comparable reductions in air pollutants. Nowak, Crane et al. (2006) estimated that urban trees at present remove 711,000 metric tonnes of air pollution (including O_3, NO_2, SO_2, CO_2) annually in the USA. This is a considerable amount and is of particular benefit, as these pollutants are removed directly from the urban environment, thus directly “cleaning up” city air. The cost to society of this carbon would have been $3.8 billion.

Niachou, Papakonstantinou et al. (2001) explain that as space at ground level becomes increasingly sparse and valuable, subsequently turning roofs green could become a significant source of urban greenery. In fact, planted roofs have become the only promising and stabilising choice if we are to find space to add greenery to cities in order to mitigate dangerous and uncomfortable urban heat island effects (Kumar and Kaushik, 2005). It could therefore be argued that green roofs could become a major controller of air pollutants in city environments.

Quantification: Whilst Yang et al. (2008) have provided modelling techniques to estimate the quantification of air quality improvements through green roofs, such modelling techniques are complex and undertaking these for each project is considered difficult. Additionally, it is not something that is typically considered important for projects, as the stakeholders/client paying for the project will not necessarily be the people that will benefit the most from installation of a green roof for these benefits. It is suggested that this is only considered if explicitly stated by the client to be something of importance.

Acoustic Performance

Acoustic performance of green roofs is another area which has recently received attention (Van Renterghem and Botteldooren, 2008, Van Renterghem and Botteldooren, 2009, Van Renterghem and Botteldooren, 2011). Green roofs can reduce sound in two ways, which include providing increased insulation of the roof system, and by the absorption of sound waves diffracting over roofs (Van Renterghem and Botteldooren, 2011).

Their first paper (Van Renterghem and Botteldooren, 2008), studied the sound propagation over both intensive and extensive roofs in a homogeneous and still environment. The presence of plants was not considered in the study, therefore just the impacts of varying substrate thickness were considered. Tests were done for a street canyon situation where the source of noise was on one side of the building and the test receiver on the other. Therefore, the study was focusing on the effect of the acoustic load on the ‘sound shaded’ side of the building. The green roof substrate layers showed positive effects and showed improvements of up to 6dB at a frequency of around 1000Hz. The substrate depth was most efficient at around the maximum frequency of extensive green roofs (between 15 and 20cm). Improvements become increasingly clear at higher frequencies. Low frequencies however, were hardly affected by the presence of either an extensive or intensive green roof.

Their second study included an investigation into green roofs' potential to reduce the acoustical facade load from traffic noise (Van Renterghem and Botteldooren, 2009). The green roof orientation, type and coverage influenced the acoustic performance of buildings. Their results showed consistent positive effects by green roofs in comparison to 'rigid' roofs on the facade noise load at non-directly exposed parts of the façades. Greater attenuation is seen for higher frequencies, when traffic is moving quicker. The lower frequencies of larger vehicles were less influenced by the presence of a green roof when compared to a traditional (acoustically rigid roof). However, in the conclusions the authors state that the numerical simulations undertaken in idealised conditions are interesting to reveal qualitative trends; however the application of such results to specific situations needs caution, since quantitative predictions strongly depend on the geometric details of buildings, the building setting and the local road traffic conditions.

Both these papers investigated the acoustic benefits of green roofs through modelling procedures (Van Renterghem and Botteldooren, 2008, Van Renterghem and Botteldooren, 2009).

Their latest paper includes in-situ measurements, which found for a single diffraction case an acoustic improvement exceeding 10 dB for frequencies between 400Hz and 1250Hz for a green roof when compared to a non-vegetated roof (Van Renterghem and Botteldooren, 2011). For double diffraction cases, positive effects were measured over the full frequency range and cases up to 10dB improvement were measured. Their measurements show that green roofs may lead to consistent and significant sound reduction at locations where only diffracted sound waves arrive.

Quantitative assessment: The quantitative assessment of the acoustic characteristics tends to be done through measuring sound pressure levels in decibel (dB). Both modelling and in-situ tests before and after green roof installations have been undertaken. However, the authors of this particular study stated that such results should be used with caution, as performance will be dependent on numerous context specific variables. Whilst modelling has occurred, as shown in the first two papers above, this appears to be a somewhat involved process and not something which is going to be conducted to understand the performance at the earliest stages of design. Therefore, assumptions presented above are considered appropriate. Additionally, in BREEAM 2011, roofs with a mass of over 150kg/m^2 are not considered to require any acoustic modelling (BRE, 2011).

Maintenance

Maintenance of green roofs is a contentious issue. Intensive green roofs require increased regular pruning, feeding, weeding and watering as they are essentially a garden. Consequently, they need an increased amount of regular maintenance (Newton et al., 2007). Maintenance of extensive vegetated sedum roofs however is relatively low. This is about the same as a traditional roof of visual inspections on an annual basis (Grant, 2006b). On commercial buildings in Europe, it is generally accepted that after a number of years green roofs are not maintained, as building services managers take the view that it is not worth the expense. Such roofs then develop into more natural systems (Newton et al., 2007). Thus no increased maintenance is required in the case of extensive vegetated roofs. In fact with the increased lifespan of a green roof (approximately double that of a tradition roof) the number of times the roof has to be repaired or replaced is halved. Thus actually reducing the maintenance requirements and costs.

The Bauder guidance (Bauder, 2013a) on maintenance is all roofs require a minimum of two inspections per year to ensure that the outlets are maintained regardless of the type of green roof. Their guidance also recommends that the costs for an initial post-installation maintenance program should be included within the tender documents for a period to be agreed with the client's representative, to ensure that the green roof is healthy and fully established upon handover. The (Green Roof Organisation, 2011) UK Green Roof Code includes guidance on maintenance.

Table 3 Green roof maintenance requirements based on information from (Green Roof Organisation, 2011)

Green Roof Type	Irrigation	Fertilisation	Plant Management	General
Biodiverse – very low to low nutrition substrate	Typically not required	Generally not required, particularly where indigenous species are being encouraged to replicate native habitats. Whilst a low vegetative density is common, zero vegetation is generally undesirable	A maintenance programme should be drawn up to follow the biodiversity hypothesis, ensuring that no materials are removed from the roof that may adversely affect the biodiversity potential of the roof	Drainage outlets (including inspection chambers) and shingle/gravel perimeters to be cleared of vegetation, twice yearly.
Extensive roof maintenance - < 100mm low nutrition substrate	Post-establishment, irrigation should not be required for most extensive green roofs, although the water storage capacity of the system and the plants' water demands should be appropriately assessed.	Extensive green roofs typically have low nutrient requirements and are therefore often fertilized on an annual basis, each spring, using a slow-release fertilizer.	Removal of undesirable plant species and fallen leaves should take place twice each year	
Semi intensive – 100mm to 200mm low to medium nutrition substrate	Periodic irrigation is expected, depending upon the plant specification and the climatic and microclimatic conditions prevailing at roof level.	With a wider range of planting, using a more fertile growing medium, more regular fertilization is required.	Removal of undesirable vegetation on the greened area twice yearly.	
Intensive – 200mm + medium nutrition substrates and top soils	Regular irrigation is often required, subject to the plant specification and the climatic and microclimatic conditions prevailing at roof level.		The intensive maintenance of lawns, hedges, borders etc. is required on a regular basis, so as to maintain the roof aesthetics. Undesirable vegetation should be removed from the green areas at least twice yearly. Failed plants in excess of 5% of the plants installed should be replaced.	Drainage outlets (including inspection chambers) and shingle/gravel perimeters to be cleared of vegetation, twice yearly. Where excessive substrate settlement has occurred, this should be replenished.

Quantification: Whilst the maintenance requirements are shown in Table 3 it is considered that the most appropriate way to quantify the maintenance requirements is on the basis of cost of maintenance for different roof types. Maintenance costs should be sought from a maintenance contractor.

Structural Loads

Extensive green roofs typically add between 50 and 200kg/m2 of loading to the roof of a structure. This increase in load has to be taken by the structure of the building. Existing flat roofs however, often require no additional structural support for extensive green roof installation (Carter and Keeler, 2008). In some countries this has led to relatively common retrofitting of extensive vegetated roofs to existing structures (Kosareo and Ries, 2007). However, intensive green roofs with their greater substrate depth and provision for foot traffic require stronger structures to support their increased deadweight and live weight.

Quantification: The weights for green roofing have to take into account the saturated weights of all the materials, which can weigh significantly more than unsaturated weights. Quantification of this is relatively straight forward and can essentially be calculated by adding up the saturated weights of the various green roof components. The following tables represent typical saturated weights for the drainage layer (Table 4), the growing substrate (Table 5), and the typical weights for various types of planting (Table 6). The below information is proposed for use when calculating the structural loads in the decision tool. Through adding up the various layers the weight can be calculated. The weight of other layers as shown in Table 4 is considered negligible compared to those of the drainage layer, the growing substrate and the vegetation layer.

As the design progresses a structural engineer should consult the manufacturers of the green roof systems to gain a more accurate assessment of green roof structural loads.

Table 4 Drainage Layer Saturated Weights (Kolb and Schwarz, 1999)

Drainage Layer	Typical thickness (mm)	Weight when saturated kg/m²
Plastic tiles	25	15
with filling	40	20
with 2–8 mm burnt clay	60	25
Foam tiles	50-65	2-2.5
Foam tiles profiled	75	25
with filling	100	35
with 2–8 mm burnt clay	140	50
Foam beads with polyethylene layer	30	6
Foam beads with polyurethane layer	35	25
Gravel per 100mm	100	150-180
Sand and gravel per 100mm	100	150-180
Lava per 100mm	100	120-140
Pumice per 100mm	100	80-120
Burnt clay (large pieces) per 100mm	100	50-70
Burnt clay (small pieces) per 100mm	100	60-80
Recycled ceramic tiles per 100mm	100	110-130
Clinker (from coal burning) per 100mm	100	90-110
Foamed glass per 100mm	100	25-35

Table 5 Growing Substrate Weights (Kolb and Schwarz, 1999)

Growing Substrate	Thickness (mm)	Weight when saturated (kg/m²) per 100mm
Treated top soil for intensive green roof	100	150-200
Open pore substrate for intensive green roof	100	100-130
Open pore substrate for extensive green roof, high density (lava, recycled roof tile)	100	140-180
Open pore substrate for extensive green roof, low density (burnt clay)	100	80-130
Layered mix (pumice, burnt clay)	100	70-100

Table 6 Vegetation Layer Weights (Vegetation only) (Kolb and Schwarz, 1999)

Vegetation Layer	Required depth of substrate (mm)	Typical weight (kg/m²)
Extensive green roof of grasses, moss, sedum, etc.	50-100	10
Extensive green roof of soil covering plants and small shrubs below 0.5 m	100-150	15
Intensive green roof of larger plants and small shrubs below 1 m	150-200	20
Intensive green roof of larger plants and small shrubs below 3 m	200-400	30
Intensive green roof of large plants and small trees below 6 m	400-1000	60
Intensive green roof of large plants and small trees below 10 m	>1000	150

Costing

Capital Costs: Green roofs typically have higher capital costs than their traditional counterparts. This is particularly true in the UK, as they are relatively uncommon at present. The high initial investment in green roofs is a barrier to a widespread use, and much would be gained if extensive green roof systems could be installed at a lower cost (Emilsson and Rolf, 2005).

Emilsson and Rolf (2005) looked into the different establishment methods of thin extensive green roofs. They considered the establishment methods for extensive green roofs in Sweden, which are dominated by prefabricated mats, which is generally one of the most expensive ways of vegetating a building. They are however, low risk as they ensure instant high plant cover. The cost of the vegetation mats in Emilsson and Rolf's (2005) study was twice that of shoot establishment and close to 30% more expensive than plug plant establishment. This shows that the type of establishment can have significant impact on the capital costs. In Germany, where most of the development of technology related to production and establishment of green roofs has taken place, onsite construction is common and thus green roofs are cheaper. The development of reliable onsite establishment methods that establish high plant cover could be a way of reducing capital costs to increase the common uptake of extensive vegetated roofs. However, this does mean that the roof may not be green as soon as the building is complete.

Quantification: Capital costs for extensive green roofs are generally between 150-200% more expensive that traditional roofs (see Table 7). Intensive roofs are around 200% more expensive; however this does not include the cost of the stronger structure that is likely to be required to take the increased loads.

Table 7 Capital costs of UK vegetated and traditional roofs / m2 (Spon, 2012)

Type of roof	Cost / m2
Single layer polymer roofing membrane	£79.00 -110.00/m2
Single layer polymer roofing membrane with tapered insulation	£96.00 - £160.00 /m2
20mm thick Polymer modified asphalt roofing including underlay	£67.00 - £90.00/m2

High performance bitumen felt roofing system	£90.00 - £110.00/m2
Sedum vegetation blanket – Intensive (high maintenance, may include trees and shrubs, requires deeper substrate layers; generally limited to flat roofs)	£150.00 - £195.00/m2
Extensive (low maintenance, may include herbs, grasses, mosses and drought tolerant succulents such as Sedum)	£140.00 - £185.00/m2

Whole life costs

Several authors have looked into the lifecycle costs of green roofs. These include (Carter and Keeler, 2008). Their analysis, conducted utilising information from experimental extensive green roof test plots, showed that green roofs were 10% to 14% more expensive than conventional roofs. Their study considered quantitatively the financial cost/benefits of construction and maintenance, storm water management, energy and insulation, and air quality of extensive roofs over traditional roofs. A reduction of 20% of the construction cost would make the social NPV of the practice less than traditional roof NPV. Therefore, they strongly recommend incentives to encourage the use of green roofs. This study was conducted in Athens, Georgia, USA.

Another USA based study considers the green roof economic benefits of increased roof longevity, reduced storm water runoff, decreased building energy consumption and air pollution benefits at the building scale. Their study shows that without considering air quality the NPV is between 20.3 and 25.2% less than a conventional roof. Improved air quality considerations lead to a mean NPV for a green roof of between 24.5 and 40.2% less than a conventional roof. Again, the importance of not having to replace the membrane under the green roof is highlighted and this accounts for the majority of the savings. The study calculates the savings using a variety of methods and takes the mean values to provide the above figures. The variations show the sensitivity of such analysis to changes in assumptions. Additionally, the probabilistic analysis uses several different techniques to estimate cost benefits, for example with respect to energy use, there are three assumptions utilising different procedures; one based on a resistance model based on experimental data for Madrid (Saiz et al., 2006), the other utilises the EnergyPlus model (Sailor, 2008). Possible reasons for the difference between this analysis and that of (Wong et al., 2003b) are that no assumption was made for annual maintenance, which was accounted for by Wong et al.

Other life cycle cost analysis studies have been conducted, including one study in Singapore (Wong et al., 2003b). In their study, they considered the differences between inaccessible and accessible roofs. For inaccessible roofs they compared an extensive roof with an exposed flat roof. With respect to an accessible roof they considered a built up roof, in comparison to two types of intensive green roof; one containing appropriate green roof build up for shrubs; the other for trees. Considered in both were the initial costs of the roof systems, the maintenance and replacement costs. For all options, payback period, savings to investment ratio, and also the adjusted rate of return was calculated. Table 8 shows the summary of net savings for each option. The “LCC” does not include energy savings, whilst the “LCC (energy)” does. As can be seen, the extensive roof (when considering energy savings) is the only option to provide a positive net saving. However, all the options are highly dependent on the assumptions used.

Table 8 Summary of net savings of different green roof options (Wong et al., 2003b)

Type (%)	Inaccessible Extensive	Accessible Intensive (shrubs)	Accessible Intensive (trees)
Initial Costs	-82.5	-36.0	-49.8
LCC	-2.4	-50.3	-93.3
LCC (energy)	+ 8.5	-22.4	-42.6

Other studies have looked at the WLC of green roofs if implemented on a larger scale and the impacts of installing green roofs on 20M ft^2 of roofs by 2020 (Niu et al., 2010). They considered the cost benefits of storm water reduction benefits, based on storm water infrastructure savings (operational and also the impacts of reduced sizing). Additional savings were calculated based upon heat flux calculations and, on a building scale, the energy reductions. The most significant breakeven consideration was the need for the replacement of the conventional roof, whilst the prolonged life of the green roof means no replacement is required during the assumed 40 year design life. This was scaled upon and also considered with the reduced sizing methods for air conditioning. Additionally, the costs of the impacts of CO_2, NOx and sulphur dioxide emissions were quantified and the health benefits of NOx uptake were translated into health benefits. The outcome was that the NPV was 30-40% less than traditional roofs, thus saving significant money at a city scale over the lifetime of the green roof (considered to be only 40 years). Whilst this study provides an interesting overview of the potential scaling effects and the positive implication on a city scale; clients, developers and the immediate stakeholders of a project are not likely to be as interested in this for a single building. Additionally, this is highly context specific and built-upon a significant number of assumptions. For example, no green roof maintenance costs were considered in the study.

Quantification: Whole life costs will be quantified based on the following assumptions:

- A user specified discount rate. An assumed discount rate of 5% will be used, based on that of other authors (Wong et al. 2003 and Niu et al. 2010).
- The capital costs of the systems to be compared. Values specified in the research and cost estimates as described in the cost section will provide initial values, which can be updated by the user if more information is available.
- Annual maintenance costs as specified through research and consultation with maintenance providers. Possible to overwrite this value if more information is available.
- The modelled energy saving costs and reduced roof replacement costs for a building with a design life of 50 years, which is assumed to be appropriate for the context of large international projects.

Marketing/Publicity Value

Green roofs also offer other benefits that are associated with typical sustainable building design, which include increased property values, increased marketability of a property and business-related cost savings (Wong et al., 2003b, Kibert, 2008). Additionally, whilst there is not much academic research looking at the marketing potential of green roofs, it was mentioned as a driver for a number of the green roof case studies located in the City of London (City of London Corporation, 2011).

Quantification: Whilst this is mentioned in the literature, this is highly context specific and difficult to quantify generically, therefore is included here as a consideration for the decision maker.

Amenity Space

Various sources refer to the amenity space that green roofs can provide. Whilst this is generally limited to intensive roofs, it is an important consideration as they can potentially, if appropriately designed, provide garden space at roof level. Such green roofs are often referred to as roof gardens, or recreational living roofs in the case of the London Green Roof technical guidance (Greater London Authority, 2008). They state that enhancing amenity value as one of a number of reasons for encouraging the implementation of green roofs in the city of London. This is further emphasised as important, as with planning policies driving an increasingly compact and dense urban form there will be proportionally less space for immediate gardens, and thus accessible roof space is important in a well-designed, high quality, high density, efficient and liveable city.

Additionally, in the 17 green roofs referenced in the “City of London Green Roof Case Studies” (City of London Corporation, 2011), 9 of the case studies referenced amenity space as a driver for the installation of a green roof or a benefit of the green roof after installation. This represents a significant proportion of the intensive green roofs outlined in the study and therefore warrants consideration. Additionally, from The International Green Roof Database (greenroofs.com, 2013), which contains around 1400 green roof projects with a total green roof area of around 2,900,000m^2, around 85% of Intensive roofs are accessible, demonstrating that they are providing amenity space for the occupants of the building.

Quantification: Methods of quantifying the value of the amenity spaces that green roofs can provide is not well documented across the literature. The value of amenity space offered by accessible roof garden is not quantified in whole life costing research that has been undertaken into green roofs as outlined in the section of this Appendix labelled “Whole Life Costing”. However, amenity space can be quantified relatively easily as the area of accessible space on a roof.

Psychological Benefits

There are clear health benefits arising from the green roofs ability to reduce urban air pollutants. Additionally, they also provide further opportunities in relation to health care environments. Studies summarised in Wong, Tay et al. (2003b) have referenced research that has shown patients’ recovery rate can be faster where they have a view to a landscaped setting as opposed to a view of just adjacent buildings. *“Roof gardens can achieve cost savings indirectly by improving medical outcomes like reduced infection occurrence, reduced intake of costly strong analgesics, also some patients might be moved sooner from intensive or acute care to less costly care units”* (Wong et al., 2003b).

Quantification: It should be noted that whilst there are lots of studies on the psychological benefits of greenery and the proximity of greenery to buildings and the view for internal spaces, this is an extremely context specific area of research, which is considered a potential area of future study. The author considers that this is not directly considered in this research, although maybe indirectly considered through assessing attributes such as roof aesthetics, and also the ability of the roof to provide amenity space.

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Appendix M Cool roofs additional literature

This appendix provides a literature review on cool roofs. It expands on the information in Section 3.6.3 of the main body of the thesis.

Cool Roofs

Cool Roofs have benefits at multiple scales. At a city scale this includes *"Substituting a cool roof for a non-cool roof decreases cooling-electricity use, cooling-power demand, and cooling-equipment capacity requirements, while slightly increasing heating-energy consumption. Cool roofs can also lower citywide ambient air temperature in summer, slowing ozone formation and increasing human comfort."* (Akbari, 2008). There are also secondary advantages to increasing the albedo of urban surfaces. The resulting lower urban temperatures improves air quality and decreases smog in cities - the probability of smog increases by 6% per °C increase in temperature above a threshold of 22°C (Rosenfeld et al., 1995). Preliminary calculations show that a moderate change in surface albedo in the Los Angeles Basin could reduce smog by around 10% - the equivalent of removing 10 million cars from Los Angeles roads (Rosenfeld et al., 1995).

However, recently there has been interest on increasing world-wide urban albedos to offset CO_2 emissions that contribute to global warming. The high albedo of roofs and paved surfaces have the potential to increase the albedo of urban areas by 10%. If this was done globally across all urban areas, there would be a negative radiative forcing equivalent to offsetting about 44Gt of CO_2 emissions (24Gt by roofs, 20Gt by pavements) (Akbari et al., 2009). Using the current rate that CO_2 is traded at in Europe at approximately $25/tonne, this is worth approximately $1,100 billion (Akbari et al., 2009). Additional benefits from reducing temperature and buildings' cooling energy use, include a reduction in peak power demand, which means that fewer power stations are required. For example, in Los Angeles peak cooling demand increases by 3.0% for every 1°C rise in are temperature above 18°C, and across the US, heat islands raise air conditioning demand by about 10GW annually costing billions of dollars annually (Rosenfeld et al., 1995).

Rosenfeld, Akbari et al. (1995) suggest that the costs of increasing the albedo of a city are quite low if performed during routine maintenance. Roofs are typically refinished every 10-20 years and cooler roofing material is either available or can be developed at very little increase in cost. Additionally, they state how light coloured surfaces suffer from less damage caused by daily thermal expansion and contraction. UV damage is also reduced because this form of damage is caused by free radicals which interact more strongly the warmer the material.

Rosenfeld, Akbari et al. (1995) suggested policy steps to implementing cool surfaces and shade through trees some of which have now been achieved with various levels of success. Today these include cool roofing standards now in the USA. (Akbari, 2008).

Quantitative Assessment:

The 'coolness' of cool roofs is normally measured by utilising the Solar Reflective Index SRI of the material. The SRI is calculated utilising the ASTM E1980 – 11 Standard Practice for Calculating Solar Reflectance of Horizontal and Low-Sloped Opaque Surfaces (ASTM, 1980b). The Solar Reflectance Index (SRI) is a measure of a material's ability to reject solar heat, as shown by a small temperature rise. Standard black (reflectance 0.05, emittance 0.9) is 0 and standard white (reflectance 0.8, emittance 0.9) is 100. A standard black surface would typically have a temperature rise of 50°C in hot sun, and a standard white surface has a temperature rise of 8.1°C in full sun. Materials with the highest SRI are the coolest materials. Because of the way the SRI is calculated, particularly hot materials can take slightly negative values, whilst particularly cool materials can take values above 100.

However, quantitative assessment of the benefits of roof albedo and thermal emittance is not a trivial process. It is complicated by the following (Suehrcke et al., 2008):-

- the heat flows, due to solar absorption and outside to inside air temperature difference, are variable and influenced by the thermal mass of the roof;
- the solar absorbance of a roof will change with time due to dust and aging;
- if the roof is shaded (by trees, clouds or other means) the amount of incident sunlight is reduced, which tends to reduce the potential of cool surfaces (Akbari et al., 2009);
- effects such as surface roughness and small amounts of impurities in the material can lower the reflectance and albedo of a surface (Berdahl and Bretz, 1997).

Despite this, equations have been derived for quantitatively assessing the effect of roof albedo and infrared emittance on roof temperature and internal building temperature (Levinson et al., 2007). Tools are available for assessing the potential energy reductions such as the Energy Star Roofing Comparison Calculator (US Environmental Protection Agency, 2004). Techniques are available for modelling the impact of the Solar Reflective Index, a combination of albedo or solar reflectance and emissivity, and these are typical in building simulation packages such as EnergyPlus. There are also some simpler tools that are available such as the SRI calculator written by Ronnen Levison and Hashem Akabari (Levinson, undated), which use the Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces (ASTM, 1980a), however these do not give you the dynamic performance of the impact of roof albedo over a year, rather the performance at a point in time.

A directory of thousands of different roof products and their associated SRI has been compiled called the “Energy Star Roof Product List” (Energy Star, 2013). This includes over 4300 roof products across numerous different roof types. For each product it has the information shown In Table 1.

Table 1 Energy Star Product Database Fields with Description taken from (Energy Star, 2013)

Field	Description
Energy Star Partner	An organization that signed a Partnership Agreement with EPA to manufacture or private label ENERGY STAR qualified product
Brand	An identifier assigned by the manufacturer or private labeler to a product or family/series of products for sales and marketing purposes.
Model Name	An identifier assigned by the manufacturer or private labeler to a product or family/series of products for sales and marketing purposes.
Model Number	A distinguishing identifier, usually alphanumeric, assigned to a product by the manufacturer or private labeler.
Additional Model Information	An identifier assigned by the manufacturer or private labeler to a product or family/series of products for sales and marketing purposes. This column includes alternative means to identify the model/model family (e.g., additional model names, additional model numbers, retailer SKUs, product descriptions).
Product Type	Defined as the following roof types: - Built-Up-Roof (BUR) - Coating - Metal - Modified Bitumen - Shingle - Single-Ply Membrane - Spray Polyurethane Foam Roof System - Tile
Initial Solar Reflectance	The fraction of direct and diffuse radiation from the sun reflected by a surface expressed as a percent or within the range of 0.00 and 1.00.
Solar Reflectance after 3 years	The fraction of direct and diffuse radiation from the sun reflected by a surface, weathered for a minimum of three continuous years, expressed as a percent or within the range of 0.00 and 1.00.
Initial Emissivity	The relative ability of a surface to emit energy by radiation, expressed as a percent or within the range of 0.00 and 1.00. Typically, the larger the emissivity value, the greater the energy savings.
Steep Slope?	Suitable for surfaces with a slope greater than 2:12. Products that are typically installed on steep-slope surfaces include composite shingles, clay, concrete, or fiber-cement tile, slate, metal panels, and metal shingles. Some products that are typically installed on low-slope roofs may also be installed on steep-slope roofs (e.g., single-ply membranes and roof coatings).
Roof Cleaned Prior to 3rd Year Test	As of December 31, 2007, the test surface of each roof product sample shall not be washed, cleaned, or wiped in any fashion prior to testing solar reflectance after three years. Loose dirt, embedded dirt, environmental stains, mold, mildew, and any other material that rests on – or has become incorporated into – the surface of the material shall not be altered. Roof products cleaned prior to third year test indicate "Y."
Warranty Period (Years)	Each company's warranty for ENERGY STAR qualified roof products shall be equal in all material respects to the product warranty offered by the same company for comparable non-ENERGY STAR qualified roof membrane products. A company that sells only ENERGY STAR qualified roof products shall offer a warranty that is equal in all material respects to the standard industry warranty for comparable non-ENERGY STAR qualified roof products.
Date Available on Market	The date that the model is available for purchase.
Date Qualified	The date on which the product was confirmed to meet the ENERGY STAR specification.

Assessment of performance should be done in accordance with the climate and various environmental factors. Performance can be assessed in terms of:

- Roof surface temperature
- Flux into the urban environment. This is a proxy to urban heat island effect, although due to many other variables involved in determining urban temperatures, this is not directly related and only partially influences urban temperatures.

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Appendix N Solar technologies additional literature

This appendix provides further information regarding solar technologies. It should be read in parallel to Section 3.6.4 of the main body of the thesis.

Solar Thermal

Quantitative Assessment:

Quantitative assessment of the performance of Solar Thermal Collectors (STC) can be done in several ways. The simplest includes utilising system efficiency for converting Solar Radiation, incident on a surface, into usable energy in the form of hot water. Typical system efficiencies range from 40-60% for the conversion of solar radiation into energy in the form of hot water (CIBSE, 2007).

The solar radiation incident on a surface is normally relatively easy to calculate utilising a weather file. This will vary based on location, inclination and orientation but this can be easily calculated using a simple model or the Energy Plus simulation software for a given location. Therefore, the following simple equation will be used to assess the performance of the Solar Thermal Performance.

$$E = A.\,f_{active}.\,G_T.\,\mu_{system}.\,t$$

Table 1 Nomenclature for calculating Energy Savings due to hot water production by Solar Thermal Systems.

Mathematical Variable	Description
E	Hot water Energy Produced (Wh)
A	Net area of surface (m^2)
f_{active}	Fraction of collector area with active solar cells
G_T	Total solar radiation incident on array [W/m^2]
μ_{system}	Solar Thermal System Efficiency (30-60%)
t	Time at that solar radiation

Unlike Solar PV, however, where typically the output of systems is unlikely to match the demand of the building, in the case of Solar Thermal collectors, due to the increased efficiency and also the demand for hot water in some building types being relatively low, for example office buildings, it is possible to oversize the systems relatively easily, so that they produce more hot water than the building requires. Unlike electricity, hot water is harder to transport, and transport losses are considerably higher than electricity. Therefore, to avoid over production, systems are often design to meet the peak hot water demand on the sunniest day of the year. This means that for less sunny days, the solar thermal system is unlikely to meet the building's typical daily demand. This sizing method aims to ensure that all the hot water produced by the system, is utilised in the building and thus minimise the oversupply of hot water from solar energy. This sizing is considered a design element rather than a roof selection element and therefore not considered in this research. It requires much broader consideration than just the roof selection, and requires the hot water demands of the building to be assessed. Additionally, long pipelines should ideally be avoided to ensure losses in the building are minimised. Zhai, Wang et al. (2008) state that the integration of solar thermal collectors into the building's roof has the disadvantage of serious thermal loss led by long pipelines. Again, this is considered beyond the scope of this research to be considering the pipe runs and losses within the building.

Solar PV

Quantitative assessment:

The quantitative assessment of the performance of Solar PV systems can be done at several levels of abstraction and there are many variations on the methodology described below to calculate the energy production and power produced.

The following equation is generally used and is taken from the EnergyPlus Engineering Reference Guide (Lawrence Berkeley National Laboratory, 2013):

$$P = A.f_{active}.G_T.\mu_{cell}.\mu_{inverter}$$

Table 2 Nomenclature for Simple Photovoltaic model (taken from Energy Plus Engineering Reference (p1111) 13/10/2011

Mathematical Variable	Description
P	Electrical power produced by photovoltaics (W)
A	Net area of surface (m^2)
f_{active}	Fraction of surface area with active solar cells
G_T	Total solar radiation incident on PV array [W/m^2]
μ_{cell}	Module conversion efficiency
$\mu_{inverter}$	DC to AC conversion efficiency

This is then converted into energy produced by the system by multiplying the electrical power produced (P) by the amount of time (t) it produced that power as shown in the equation below.

$$E = P.t$$

This calculates the output utilising the sites annual solar incident radiation. The efficiency of different panels is often calculated under Standard Test Conditions (STC) of 1000W/m2 at a specific temperature (25degC), with a certain spectrum of light (International Electronics Commission, 2008). From this the efficiency is calculated. This is generally a good enough approximation of the performance of systems for calculating the energy production from the system. From this, costs and paybacks can be rapidly calculated based upon a few assumptions such as unit cost of electricity for a particular region.

This model ignores reductions in the efficiency of PV systems when hot. Whilst, this is normally relatively minor, other more complex assessments exist, which also account for reductions in efficiency. These utilise the albedo and reflectivity of the systems to calculate the temperature of the panels (typically at hourly intervals) for a specific weather file and utilise this to calculate the drop in performance. One such technique that does this, which is integrated within the EnergyPlus building simulation program, is the “Sandia” Model based on the work done at the Sandia National Lab by King et al. (2004). This is a much more complex model and utilises the performance of real test panels to define empirical relationships for predicting the electricity generated. For further information see (King et al., 2004). It is proposed that for standardised panels that exist in Energy Plus that this method is to be used, as it is relatively common for the reductions in efficiency, due to high panel temperatures, to be of concern. Additionally, through the Sandia method, the temperature of the panels can be assessed and this could potentially be useful when calculating the impact on the urban heat island effect.

Whilst the energy produced can be quantified relatively accurately utilising the above equations, there can be further benefits, which are harder to quantify. Keirstead (2007) terms this the 'double dividend' effect, which is providing renewable energy as well as encouraging more efficient energy use. Their findings show that energy use decreases by 6% when home owners install PV. However, their findings are based on individual home owner's personal perceptions and not on measured data.

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Appendix O Description of quantification of attributes

This appendix provides further information on the quantitative assessment of performance in the roof attributes of the Roof DST. It should be read in parallel with the main body of the thesis.

Roof Performance Measures Details

Economics

Capital Costs

The capital cost of different roof options are to be measured in *"£ per m^2 of roof"*. Capital costs are provided based upon the most recent values from Spon (2012), which is the industry standard text for estimating costs for buildings in the UK.

It is accepted that these may not represent the context of the particular project of interest and thus they are provided as initial guidance in the absence of further information. However, it should be noted that these should be updated to reflect the current context in the location of the project of interest. Spon (2012) provides a range of costs and is meant for construction projects that are typically over £3.5M build costs, which represents the majority of projects that a design consultancy, such as the sponsoring organisation of this research would work on. Costs are generally given in ranges with a high cost and a low costs. Where this is the case, the average cost is the one that is taken in the first estimate cost, which generally represents the mid-point of the two extremes. This typically reflects the costs of labour as well as the materials used, which is considered an appropriate first estimate. The costs have been arranged in a small database in the decision support tool and are referenced automatically by the system to provide initial information. This can then be replaced by the user as more information becomes available.

In-Use Costs

For all flat roof options it is recommended that the roof is inspected 1 to 2 times per year. Thus the costs of doing this for different types of flat roof are ignored as they are equal. Other influences of in-use costs are likely to be the replacement for the design life of the building. In use costs should be considered on a case by case basis.

The design life should be specified at the start of the decision making process. The default assumption is 60 years based upon that being the standard assumption for buildings in the UK. Therefore, the replacement costs should be considered. This accounts for the NPV of the replacement costs, assuming the same costs as the today's costs and a discount factor, which is defined by the decision maker. An arbitrary discount factor of 4% is suggested. It is highlighted that there is the possibility of double counting, as the design life is used to account for durability. Therefore, the decision maker should either consider this under this attribute of in-use costs, or instead consider this separately under durability. This should be made explicit to the decision maker.

For Photovoltaic and Solar Thermal Systems applied onto roofs, other influences on the in-use costs include any energy generated or saved by the different roof systems. This can be relatively easily converted into costs through multiplying the units of energy produced by the cost of the energy type it is displacing (i.e. electricity or gas). PV is considered to be displacing electricity, and hot water produced is assumed to be replacing gas heating with a 90% efficiency. Unit electricity prices and gas prices vary significantly and there is the option to put this in manually. However, prices assumed should be based on the most up to date energy prices. At the time of writing the UK cost of electricity and gas is stated in the Quarterly Energy Prices June 2013, National Statistics. (Department of Energy and Climate Change, 2013) This can be over-ridden by the user of the decision tool. Again it will be made explicit to the decision maker that unless the energy produced is removed from the analysis this could be classed as double counting as the energy produced is a main factor in determining these costs. NPV calculations are not done for this as it is assumed that energy prices will rise in the future and thus this will offset the discount factor.

With respect to green roofs, maintenance is considered on an annual basis. Papers such as Carter and Keeler (2008) and Wong et al. (2003) should be used as a starting point as to what to consider.

Social

The four considerations from a social perspective have been defined from the literature review to be as follows:

- Innovation and publicity
- Aesthetic value
- Amenity Space
- Acoustics

Innovation and Publicity

As there is no common method of assessing the innovative nature of roofs, this will be left to the consultant's discretion and it will be expected that each roof type will be given a score with respect to how much positive publicity and how innovative they consider the roof to be. It is accepted that scoring on this attribute is likely to be subjective, however that does not mean it should be ignored. In fact, providing a direct rating on this aspect, may provoke dialogue and also raise awareness in this area. This should be done on a sliding scale on a value scale, and should consider all the roof options selected for consideration. More standard roofs are considered to not score well on this scale, with accessible roof gardens and roofs with renewables scoring more highly. Consideration should be given to the uniqueness of a certain type of roofing for the context of the project. Additionally, many companies are now producing Corporate Social Responsibility (CSR) reports on an annual basis, and environmental and social aspects are often considered in these reports. Whether the roof could contribute to being mentioned in this report may also provide guidance to the design consultant as to how this score should be assessed.

Aesthetic Value

As this is a subjective and highly context specific attribute it is considered that like "innovation and publicity" this should be scored on a direct value scale with input from the project's stakeholders. In order to provide guidance on this, a set of images of different roof types is provided in the decision support tool and the user is asked to score the aesthetics of the roof types on a 5 point scale. The average scores across stakeholders are then taken as scores for each roof type. This is incorporating the stakeholder opinion to provide the scoring on a project by project basis. It is proposed that such a technique could be used at a client meeting and automatically input into the tool.

Amenity Space

The variable used to measure the amenity space is *'m^2 of accessible roof space'*. Accessible, means that there is easy access to the roof, including edge protection and that the space is suitably designed for loading. Roof types include those of semi-intensive and intensive green roofs and also roofs with a concrete finish, which can provide amenity space. Whilst this does not account for the quality of the amenity space, it provides some measure, and quality of the amenity space is likely to be highly subjective. Additionally, the value of the amenity space is likely to change significantly depending on the location of the building and the value of adjacent land. However, this is not reflected in this measure. However, if this is important to the project, this can be reflected by increasing the weighting of this particular attribute. Weightings are discussed in more depth in the next section. Whilst the score will depend upon the accessible area for general use the roof types which have been classified as being accessible are as follows:

- Paved roofs
- Intensive green roofs

All other green roof types are not considered accessible space and thus will not be scored as such. Whilst, the roof type will gain scores for accessibility, it should be noted that the access and edge protection will have to be suitably designed to accommodate for regular access. This is considered beyond the scope of the selection tool and a design consideration.

Acoustics

Acoustics should be considered on a case by case basis. This has not been significantly covered in this thesis; however, there has recently been some research into the performance of green roofs in this area (Van Renterghem and Botteldooren, 2008, Van Renterghem and Botteldooren, 2009, Van Renterghem and Botteldooren, 2011). This should be used as a reference set to inform decision making. Additional information is included in BREEAM (BRE, 2011) in relation to the weight of different roof systems. For example, roofs below 150kg/m^2 require calculations or laboratory data are required for learning spaces to demonstrate that the reverberant sound pressure level is 20dB above indoor ambient noise level.

Environmental

Ecology / Biodiversity

Only green roofs and brown roofs will gain any credit under this attribute. Additionally this is a difficult one to assess rigorously at the earliest stages of design. The ecological value of any roof will be dependent on the specification of the planting of the roof.

Methods of establishing the improvement in local biodiversity are established in BREEAM (BRE, 2011) (p209). This assesses the species richness (also known as the average total taxon) and takes area weighted average of the plant species richness as an indicative measure of the ecological value of the site. The same approach will be applied here to the roof area.

The same method will be used as a way of assessing the ecological value of the green roof with data for green roofs outlined above, providing information to inform the decision maker. However, it should be noted that the BREEAM methodology only counts the contribution of a green roof if a suitably qualified ecologist has been appointed to advise on suitable plant species for the roof. Additionally, the way that BREEAM awards points is dependent on the change in the average total taxon of before and after the development. Whilst this will be considered when calculating potential BREEAM points at an early stage, it will not be considered when assessing the ecological value of the different roof options alone.

Values in the table below will be utilised unless over-ridden by the user.

Table 1 Green Roof Types and assumed species richness

Green Roof Type	Species Richness	Reference
Extensive	11	(Bauder, 2013)
Semi-Intensive	24	(Bauder, 2012)
Intensive	30 (recommended to be user specified)	

Energy

The energy attribute is split into several lower level attributes, which are calculated utilising different methods for different options. This reflects the different aspects of the higher level objective to *'minimise the projects net energy consumption'*. Whilst all attributes are summed, it is considered important to break this up as to allow the decision maker to see how the roof is performing and it is useful for broader understanding of each option. This is further explained below. The energy is considered as the attribute rather than the carbon emissions associated with energy production. The reason for this choice of attributes is that the carbon emissions will be dependent on the carbon intensities of the various supply systems in the region of the project in question. This is considered outside the scope of this research to compile this information.

Energy Production (kWh/m2/annum)

This will only be considered for roof types with Solar Thermal Panels or Solar Photovoltaic panels installed on the roof. The user of the decision tool will specify the area of solar thermal panels and the roof type on which they will be installed. The percentage coverage will automatically be calculated by the tool and for panel areas above half the roof space a warning will emerge reminding the user of the tool that area is required for access and maintenance of the roof and this should be accommodated accordingly.

- **Solar Thermal Energy Production (kWh/m^2/annum).** This is calculated from utilising a rule of thumb estimate equation, which assumes a system efficiency for the conversion of solar radiation energy into hot water. Efficiencies generally range from between 30% and 60% and the user of the decision tool is asked to input an appropriate percentage when selecting the Solar Thermal option. It should be noted that the sizing of the solar thermal system will need to be done by the design consultant to be suitable for the project in question. This is outside the scope of the roof decision support tool. Appropriate sizing is required, as the objective is not necessarily to maximise Solar Thermal Energy Production, as a system that is oversized for the hot water demands of the building on the peak summer day can be problematic. Oversizing can easily be achieved for buildings where the hot water demand can be low such as office buildings, or where summer time hot water demand is low, for example schools. It is assumed that oversizing will be avoided by the design consultant and therefore the system that produces the most hot water will get the highest score.
- **Solar Electric Energy Production (kWh/m^2/annum).** This is calculated utilising the equation as defined in Appendix T for self-specified efficiencies. For known efficiencies the Sandia Model (King et al., 2004) is used and implemented by the building simulation program EnergyPlus. This provides a more accurate representation of performance. The decision support tool also provides hourly information of performance over the course of a year. The 8760 hourly data points are then summed to provide an annual figure for performance. This accounts for the area and type of PV specified, the climate (utilising the closest weather file), location and pitch. The advantages of utilising a Sandia Module (King et al., 2004) for performance is that the surface temperature of the photovoltaic panels can also be assessed and thus an approximation of the contribution to the Urban Heat Island attribute can also be assessed as well. More information on the use of EnergyPlus and the assumptions used and how the information is managed are included in Section 12.10, which discusses the tool development.

Building Energy Use (kWh)

This is calculated for a reference building for all climates and all roof types. On the reference building, to assess the impact of different roof options, all assumptions remain the same across all model runs. The only changes in each case are to the roof finish applied. For consistency, an identical level of insulation is also applied across all the models.

The model output includes the heating and cooling load required to maintain the room at a temperature between 20°C and 24°C. The combined amount of the heating and cooling load is taken as the reference figure. This provides a context specific estimate of the relative energy saving impacts that can be attributed to the roof system and should reflect the climate of interest as defined by the tool.

Urban Heat Island Effect

The urban heat island effect is assessed utilising *'roof surface temperature (°C)'* as a proxy measure. Other criteria that have been utilised by others to assess the impact of UHI includes a combination of the roof albedo (reflectivity) and emissivity as combined into the Solar Reflective Index (SRI). The issues with this are that it does not reflect all the mechanisms of heat transfer that are involved in green roofs, which include transpiration and evaporation. Another proxy measure of the urban heat island impact of different roof types is the sensible flux into the built environment as discussed by (Scherba et al., 2011). However, this is complicated to calculate and, whilst it is possible utilising the Energy Plus Package, is still a somewhat proxy measure of the impact on urban heat island effect, which is extremely complicated and dependent on many other parameters including the local buildings etc. Therefore, as a compromise, roof surface temperature is utilised as a proxy measure. This is calculated utilising EnergyPlus for the nearest weather file to the project by the decision support tool.

Water quality

Whilst there are several areas of research outlined as important, there are no formulae currently identified across the research for calculating the quality of water runoff from roofs. Therefore, if water quality is considered an important decision attribute, research should be looked up to inform the values used for use in the decision.

Water Retention

Water retention will be assessed in the same way as outlined in the (FLL, 2002) utilising the average annual percentage retained as shown in the Appendix R, and will be assumed applicable for green roof systems only. Other systems will be assumed to have a water retention of zero. The values used in the FLL, will be adjusted to reflect the local context and the type of roof system according to the most applicable local research.

Water Detention

Water detention would only be a consideration for green roofs and roofs with water storage capacity. For more information see Appendix R.

Rainwater harvesting

Rainwater harvesting is included in the tool, as it is something that is often considered when assessing a roof space. There is a British Standard for undertaking rainwater harvesting design (BS8515, 2009), which is followed when considering the runoff for different roof types. However, there is no focus given to sizing the system and the scoring in the decision tool only considers the potential input from rainfall considering the roofs runoff coefficient.

Watering requirements

This attribute will only be calculated for the various green roof types. All other roof types will be assumed to be consistent and require no water.

Watering requirements for green roofs are not trivial to calculate and not much research has been undertaken. They are also highly context dependent on local planting and numerous climatic variables, such as temperature, humidity and wind amongst many others. Methodologies for calculating the watering requirements have been studied with a primary focus on water required for crop production by the Food and Agriculture Organisation (Allen et al., 1998).

However, the moisture balance is an important element of the thermal heat transfers that occur and has therefore been modelled by Sailor when creating the thermal performance model for Energy Plus (Sailor, 2008). This takes into account the regional context and local climatic variables of the weather file. Unfortunately, rainfall is not often included in the weather file and thus the model assumes no rainfall. It does however calculate the amount of water required to keep the soil at a standard 40% saturation. For this reason, the outputs cannot be directly used to determine the amount of watering required. Instead, this value will be used and it will be assumed that the proportion of the annual rainfall attenuated by the green roof will provide the plants with some of their requirement for water. This will therefore be subtracted off the water requirement as determined in Sailor's model. The value will be given in litres per m^2 per annum.

Materials

The materials attribute is split into three sub attributes, which are as follows:

- Embodied Carbon ($kgCO_2/m^2$)
- Durability (years)
- Structural loading (kg/m^2)

It is not argued that this is complete; however this will be providing much more rigour than is typically assessed in the design process for roofs. Additionally, the selection of materials for roof systems could be a doctorate in its own right. Furthermore, information on many of the above categories is not yet available for all roof types and thus, depending on the decision context may not be able to be retrieved. However, the green guide to specification has undertaken life cycle analysis of approximately 500 roof constructions with the same functional units, meaning that the information is comparable. This provides a good dataset for many roof types to inform roof selection. Whilst this provides an excellent reference, it does not cover operational improvements that could be attributed to the different roof choices, for example building in-use energy consumption (Anderson et al., 2009). This will ignore aspects such as the albedo of the roof and its potential impact on energy consumption. Additionally, there is no mention of green roofs in the green guide to specification, and therefore additional consideration needs to be given to green roofs.

The attributes are discussed individually below and can be separated if desired. Additionally, it is proposed that the green guide overall rating can be applied at the materials level of the hierarchy, if desired by the decision maker.

Embodied Carbon

The embodied carbon of the different roof options is included in the Green Guide to Specification and these values have been incorporated into the roof selection tool. They range from -4 kg CO_2/m^2 (Structurally insulated timber panel system with OSB/3 each side: roofing underlay, counter battens, battens and reclaimed clay tiles – for healthcare) to 290 kg CO_2/m^2 (In situ reinforced concrete slab: oxidised polyester reinforced bitumen roofing membranes, insulation, paving slabs – for a domestic property). This shows a significant difference across different roof types and some build-ups being classed as carbon negative due to the reuse of existing materials.

For flat roofs the minimum embodied CO2 was 15 kg CO_2/m^2 (for vapour control layer, insulation, timber joists, OSB/3: EPDM single ply roofing membrane for domestic sector). Therefore, significant difference is evident. The green guide contains a significant number of typical roof constructions; however it does not include any green roofs which are not mentioned in the guide. Fortunately, there are open source databases of the embodied carbon of construction materials (Hammond and Jones, 2008). The databases, called the Inventory of Carbon and Energy (ICE) is based upon academic references, where a clear methodology has been adopted. The current version (V2.0) contains over 200 materials and is freely available to download as an excel file (Hammond and Jones, 2011).

Getter et al. (2009) utilise information from this database to calculate the embodied carbon in extensive roofs, utilising assumptions on the root barrier being similar to LDPE, the drainage layer being made out of polypropylene and the substrate being half sand and half expanded slate with a depth of 60mm. After undertaking simple calculations, a figure was derived of 6.6kg CO_2 /m^2 for a green roof system. This is to sit on top of a standard roof membrane. They do point out in their paper that many traditional roofs would have a gravel ballast, which is no longer needed on a green roof. Simple calculations show a gravel ballast with a depth of 20mm would typically be associated with around 0.017kg CO_2 /m^2. However, one should note that the ICE methodology for estimating embodied carbon includes a “cradle to gate”, which accounts for embodied carbon for all processes and extraction techniques from extraction to leaving the factory gate. It does not therefore account for transportation to site, maintenance or replacement, which is covered in the Green Guide to Specification (Anderson et al., 2009).

Getter et al. (2009) also calculate the carbon sequestration of extensive green roofs to be on average around 0.375 kg CO_2 /m^2. Whilst significantly less than the embodied CO_2 of the system, if done on a wide scale could be a small but significant potential for carbon sequestration. Additionally, it should be noted that whilst the sequestration potential does not cover their embodied carbon impact, the thermal benefits of the system on reducing building cooling and heating loads was stated by Getter, Rowe et al. (2009) to typically payback the embodied CO2 within 7-9 years. Additionally, other benefits such as improved roof life span are not accounted for in this methodology.

Therefore, with respect to embodied carbon, the carbon of the constituent parts of the green roof systems, as calculated utilising the values from the ICE database (Hammond and Jones, 2011) and used by Getter, Rowe et al. (2009), will be added on to the embodied carbon of the specific system from the Green Guide to Specification. Whilst differences in methodology are evident across the ICE database and the Green Guide to Specification, the figures are not perfect and will not cover the maintenance requirements of the green roof, which will require people to visit the roof at least twice a year for inspections and to provide fertilisation and care during the establishment period. However, until further information on the embodied carbon of green roofs is available then this provides the best available information. It should be noted that the embodied carbon was estimated for the UK fuel mix, therefore results are more applicable for use in the UK. Additionally, the Green Guide to Specification utilises a LCA methodology that is accepted for the European Context. Again whilst not generalisable to all regions, they will provide more accurate information than is currently available for the early stages of concept design for the global context.

With respect to the embodied carbon of photovoltaic systems, many papers have been published for the USA (Zhai and Williams, 2010), India (Zhai and Williams, 2010, Nawaz and Tiwari, 2006) and the UK (Hammond et al., 2012).

The Indian study will not be utilised in this instance, as the analysis was conducted for a system with batteries. This research assumes that all systems will be connected to the grid and therefore will not require batteries. The results vary significantly across the studies. The Hammond study is the most up to date and will be taken as the example to be used in this case. The example assumes that the system would displace concrete tiles, and this is taken to be approximately 1900MJ of energy. The total system in there example was 83,000MJ. Therefore, this has to be added on if not considered displacing existing tiles. Thus the embodied energy of the system is 84,900MJ. This assumes for the entire life cycle and includes transportation from Asia to Europe and a 200mile van journey.

Based on rules of thumb estimates, the embodied carbon for 1m^2 of poly-crystalline panels including other components required for the system to be functional is approximately 195kg CO_2/m^2, based on figures from (Zhai and Williams, 2010). This is in the USA context with a carbon content for the grid similar to that of the UK. With respect to the mono-crystalline PV roof tiles, the embodied carbon was calculated based upon the embodied energy figures given by (Hammond et al., 2012). The value calculated was 262kg CO_2/m^2. The values calculated are in the range given in (Hammond and Jones, 2011), which are summarised in Table 2. The average figures as shown below will therefore be used for in the Roof Selection Tool.

Table 2 Embodied Energy and Carbon Values for PV modules (Hammond and Jones 2011

PV Modules	Embodied Energy (MJ/m^2)	Embodied Carbon (kg CO2/m^2)
Monocrystalline	4750 (2590 to 8640)	242 (132 to 440)
Polycrystalline	4070 (1945 to 5660)	208 (99 to 289)
Thin Film	1305 (775 to 1805)	67 (40 to 92)

With respect to the embodied carbon of Solar Thermal Systems, a study by (Kalogirou, 2004) quantified the embodied energy required to produce a 3.8m^2 panel, which included construction and installation. The embodied energy required was calculated to be 8700MJ or 2290MJ/m^2 of panel. This was also converted into a carbon figure of approximately 510kgCO_2/m^2 on the assumption that all energy input was produced through grid electricity. This is, as the author states, not a correct method but is likely to give a worst case scenario. Another study has been conducted that looks at the embodied energy of a flat plate collector with a storage tank and support framing for a flat roof (Ardente et al., 2005). The 2.13m^2 complete system is shown to have an embodied energy of approximately 11.5GJ of which about 4.4GJ is related to the hot water tank and 1.1GJ to the supporting structure (not included in the analysis by (Kalogirou, 2004). Removing aspects that were not considered in (Kalogirou, 2004) gives an embodied energy figure of 2380MJ/m^2 of panel, which is comparable. The entire system is calculated to have an embodied carbon of 650 kgCO_2 or 305kg/m^2. However, a large chunk of which is associated with the water storage tank, which this author argues would be required anyway and thus should be discounted from the analysis. Doing this, the embodied carbon is reduced to approximately 190kg/m^2 of collector. This is considered a more realistic estimate of embodied carbon and therefore is used as the figure within the decision making tool.

Durability

Assessing the durability of roofing materials is not a trivial process. Papers have been written outlining an approach to the selection of roofing materials for durability (Soronis, 1992). According to Soronis, the durability of roofing materials is greatly influenced by the local climate and air pollution and service life predictions are always very complex procedures. However, unfortunately there is little data included in the paper and all that is outlined is a model for assessing the optimum material based upon the cost and durability parameter. The durability parameter involved ranking the materials according to their corresponding service life. However, the technique outlined essentially involves converting all parameters to cost. This here is concerned with only two variables of durability and cost and the relationship of the two on the overall costs for the roof over the design life of the building. Whilst the ranking method is considered appropriate and is something that is loosely adopted based upon the manufacturers warrantee for the roofing system, the sustainable roof selection method presented in this paper aims to incorporate significantly more parameters than Soronis (1992). Therefore, utilising a similar technique is considered inappropriate.

For the requirements to be simplistic and quick to use through the design process, the decision tool can incorporate various proxy measures for durability. These include:

- The Green Guide to Specification has Typical Replacement Intervals and it is this that will be utilised to assess performance of roofs in this respect. If higher or lower replacement periods (or warrantees) are specified then the decision maker has the option to over-ride the data that is automatically inserted into the system. It should be noted that "typical replacement interval" does not necessarily reflect durability and takes account of other factors such as 'fashion', 'obsolescence' or 'churn'. The Green Guide has an extensive reference basis on which these replacement intervals have been calculated based on empirical data.
- Unfortunately the green guide to specification does not include information regarding green roofs. For this reason, a proxy-measure has had to be assumed and is based upon the research summarised in Section Appendix R. This assumes that application of a green roof will double the expected replacement period due to it protecting the roof from significant temperature fluctuations, UV radiation, and the direct effects of weathering.

Structural loading

The structural loading of the various options is considered to be, the weights (kg/m^2) of the various roof types above the roof membrane. The saturated unit weights of green roofs have been defined in the literature. Solar thermal and solar photovoltaic panel weights are shown below and these will be used in the decision making tool. The weights will be included for anything above the roof membrane, and thus traditional systems consisting of an outer covering will be considered to have no 'additional' weight. The only exception will be the installation of gravel on top of a roof, which will be considered in kg/m^2. The user will be asked to provide a maximum loading per m^2 for the roof, and options will either "pass" or "fail". Failed options will be highlighted red and clearly indicated in the decision making tool. Their score on other categories will stand, so as to inform the decision maker of the potential. If they are interested and the loading is above the current structural capacity, then this could inform the design team to increase the structural capacity of the roof. For accessible roofs a loading of $500kg/m^2$ will be applied, which approximately conforms to a uniform loading of $5kN/m^2$, which is recommended as a typical live loading for reinforced concrete roofs (Cobb, 2004). For combinations of roof types, the loading applied will correspond to the largest loading of all the combination of options. This is considered appropriate, as the loading does not contribute to the scoring of the different options, it only highlights the worst case structural loadings as to inform the design.

With respect to photovoltaics and solar hot water systems, loading information will be based upon a review of different systems and their loadings (Ridal et al., 2010). Loadings will be assumed to be the following based upon the heaviest systems for each type in the range;

- 0.22kN/m2 for Solar HW collectors
- 0.19kN/m2 for Solar Photovoltaic Panels

Environmental Assessment Methods

How roofs relate to the performance of Environmental Assessment Methods are included in Appendix V.

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Appendix P Roof's relationships with environmental assessment methods

The following pages expand on the information presented in Section 3.4 and detail how the environmental assessment method criteria of BREEAM, LEED and Estidama relate to roofs. These is based heavily on information taken from the respective assessment method manuals (BRE, 2011, US Green Building Council, 2009, Abu Dhabi Urban Planning Council, 2010).

BREEAM

The following credits from BREEAM 2011 New Construction Technical Manual (BRE, 2011) have been identified for their relationship to roof type.

Man 05: Life cycle cost and service life planning – 3 credits

The aim of this credit is *"to recognise and encourage life cycle costing and service life planning in order to improve design, specification and through-life maintenance and operation."*

In order to achieve more than one credit, elements in at least two of the following building components require analysis at a strategic and system level.

- Envelope: e.g. cladding, windows, and/or **roofing**
- Services: e.g. heat source cooling source, and/or controls
- Finishes: e.g. walls, floors and/or ceilings
- External spaces

Therefore analysis of cost for various roof options at a strategic level could help in achieving this credit.

Hea 05: Acoustic Performance (Building type dependent 2 – 4 credits)

Aim: To ensure the buildings' acoustic performance, including sound insulation, meet the appropriate standards for its purpose.

Specifically for schools for roofs with a mass per unit area less than 150kg/m2 (lightweight roofs) or any roofs with glazing / rooflights, calculations are required to demonstrate that the reverberant sound pressure level in these rooms are not more than 20dB above the indoor ambient noise level. This is referenced to Building Bulletin 93 during heavy rain. No calculations are required for roofs above 150kg/m2 (heavy weight roofs).

Ene 01: Reduction of CO2 emissions – 15 credits (An additional 5 credits are available if the building is carbon negative)

The aim of this credit is "*To recognise and encourage buildings designed to minimise operational energy demand, consumption and CO2 emissions."*

The way of measurement of performance is via the Energy Performance Ratio for New Constructions (EPR_{NC}), which is calculated utilising the improvement on the Target Emissions Rate (TER) utilising specific software. This requires the reporting of the total modelled operational carbon dioxide emissions in kgCO2/m2/year via the BREEAEM scoring and reporting tool.

This requires consideration of Energy Demand, Energy Delivered and the CO2 emissions.

- Energy demand measures how well the building reduces heating and cooling energy – which is influenced by the fabric heat loss and air permeability.
- Energy delivered (consumption) – measures how efficiently a building meets its energy demand – it is influenced by factors including the type and efficiency of the building services system.
- CO2 emission: this measures the amount of CO2 the building emits to meet its energy demands. It is influenced by factors including building fabric performance, systems efficiency and fuel source. This accounts for low or zero carbon (LZC) forms of energy generation.

There is a procedure for translating performance in each of the above parameters into BREEAM credits.

The roof has a part to play in reducing energy demand, through improved fabric performance and also the potential to reduce CO2 emission through the installation of on-site renewables. Whilst it is unlikely that the roof can help achieve all these credits it could have a significant influence over this. The amount of influence the roof has over this assessment issue will depend on a number of factors including the size of the roof in comparison to the volume of the building. For example a small roof on a high rise building will have a much smaller influence on the energy demand and the ability to provide a space for renewables than a low rise building with a large plan area.

Ene04: Low and zero carbon technologies – 5 credits

Four points are available. This credit requires conducting an LZC study (1 credit) and specifies LZC technologies that provide the following reductions in regulated CO_2 emissions.

Table 1 Ene 04 credits and required reductions in regulated CO_2 emissions

No of credits	% reduction in regulated CO_2 emissions
2	10
3	20
4	30

A further 5th credit is available with regard to free cooling if the building utilises any of the following free cooling strategies and the first credit within the BREEAM issue Hea 03 (Thermal comfort has been achieved):

- Night-time cooling (requires fabric to have a high thermal mass)
- Ground coupled air cooling
- Displacement ventilation
- Ground water cooling
- Surface water cooling
- Evaporative cooling, direct or indirect
- Desiccant dehumidification and evaporative cooling, using waste heat
- Absorption cooling, using waste heat.
- The building does not require any form of cooling (i.e. naturally ventilated)

The roof can play a significant role in providing an area for the location of renewables and thus this is a significant consideration. This is also highly related to the previous Ene01 credit. The roof potentially influences this credit significantly.

Pol 03: Surface water run off

The aim of the credit is, *"To avoid, reduce and delay the discharge of rainfall to public sewers and watercourses, therefore minimising the risk of localised flooding on and off site, watercourse pollution and other environmental damage."*

The issue is split into three parts:

- Flood risk (2 credits)
- Surface water runoff (2 credits)
- Minimising water course pollution (1 credit)

With respect to the BREEAM part relating to “flood risk”; the roof type has very little influence in relation to the criteria in BREEAM, which are more related to project location (i.e. locating the building in an area with low annual probability of flooding. The second part relating to, “Surface water runoff” however, is related to roofs, which typically form a large impermeable area of the site. 2 credits are available for this part. An appropriate consultant should carry out the following:

Where drainage measures are specified to ensure that the peak rate of run-off from the site to the watercourse is no greater for the site than it was for the pre-development site. This should comply with 1year and 100 year return period events. These calculations include an allowance for climate change in accordance with best practice. Another credit is available if the post development run-off volume over the development lifetime, is no greater than it would have been prior to the assessed site’s development and additional predicted volume of run-off for the 100 year 6 hour event is prevented from leaving the site using infiltration or other SUDS techniques.

Whilst the choice of roof system, will influence the runoff, as the roof is a typically a large expansive area of a building, which is subject to rainfall. Systems can be added at roof level to reduce runoff. These include green roofs and storm water attenuation systems. Green roofs provide some attenuation, however they are not considered by BREEAM and SUDS guidance to reduce peak rate runoff, as their performance during extreme events tends to be fairly similar to that of ordinary roofs (CIRIA, 2007). Therefore, the standard approach for calculating runoff as outlined in BS EN12056-3:2000 should be used, which includes calculations for runoff (BSI, 2000).

Minimising water course pollution, involves meeting several criteria, including an appropriate consultant is required to confirm that there is no water discharged from the site for rainfall up to 5mm. In the compliance notes, green roofs can be deemed to comply with this requirement for rain that falls on to their surface. However, evidence is still required to demonstrate that the 5mm of rainfall from all other hard surfaces is being dealt with.

Potentially one of the five credits in this section can be influenced by the roof systems selection.

LE 03 Mitigating ecological impact – 2 credits

The aim is to minimise the impact of a building development on existing site ecology. There are two credits available relating to the level of change in ecological value. This is measured using an average taxon (plant species) richness. The roof offers the potential to integrate vegetation and habitat types, which can contribute to the achievement of these credits. This is primarily in reference to green roofs. For a green roof to count towards the achievement of this credit, a suitably qualified ecologist should be appointed to advise on plant selection.

LE 04 Enhancing site ecology – up to 3 credits (excluding prisons)

The aim is to recognise and encourage actions taken to maintain and enhance the ecological value of the site as a result of development.

There are three credits available for all building types except prisons. The achievement requires the appointment of a suitably qualified ecologist (SQE) to report on enhancing and protecting the ecology of the site and their recommendations will be implemented. Other credits are then available if the ecologist is consulted and confirms that measures taken will result in an increase of plant species. This is calculated utilising a calculator. An increase of less than 6 plant species will score 2 credits and 6 or more species will score 3 credits.

Ecological features can be integrated into the roof level to help achieve these credits. Such features may include green roofs.

Mat 01: Materials (Building type dependent 2 - 6)

Aim: to recognise and encourage the use of construction materials with a low environmental impact (including embodied carbon) over the full life cycle of the building.

The roof is assessed across all building types and thus one credit is always available for roof type. The measurement used to assess this is the Green Guide Rating, which formulates ratings based upon life cycle assessments of different products and systems.

It should be noted that the credit accounts for the different relative proportion of materials used through taking a weighted average. For example, if the external wall area was twice that of the roof area then that would be reflected in the calculation of the score that informs whether the credit is to be awarded or not. This accounts for the difference in the importance of the roof for a low rise building with a large floor plan to a high rise building with a small floor plan.

Mat 03: Responsible sourcing of materials- 3 credits

The aim of this credit is to recognise and encourage the responsible sourcing of materials. There are 3 credits available for this. There is also a potential innovation credit, which has additional guidelines.

The measurement is done utilising the BREEAM Mat 03 calculator. The roof is one of nine applicable building elements that require assessing. The applicable materials include a range but especially applicable to roofs are, “Plastics and Rubbers (including EPDM, TPO, PVC, and VET roofing and other membranes and polymeric renders)” and Bituminous materials such as roofing membranes and asphalts. 4 points are available for each building element, including the roof. If all 9 building elements are present then the roof makes up 1/9 of the overall score.

Mat 04: Insulation

Aim: To recognise and encourage the use of thermal insulation, which has a low embodied environmental impact relative to its thermal properties and has been responsibly sourced.

The number of credits available for this issue is two. This is split into three areas, which include a pre-requisite, embodied impact and responsible sourcing. The pre-requisite includes assessing new insulation for any of the following building elements, external walls, ground floor, **roof**, and building services.

The embodied impact is calculated using an insulation index. This is calculated for each of the four elements. This involves calculating the volume weighted thermal resistance for the insulation and multiplying this by the green guide score. All the scores are then added up and divided by the total volume weighted thermal resistance. If the resulting insulation index is greater than or equal to 2, then the credit is awarded.

The responsible sourcing credit is awarded if 80% of the total volume of the thermal insulation used in the building elements is responsibly sourced.

Due to the calculation procedure the impact of the roof insulation on the achievement of this credit will be significantly influenced by the amount of insulation in the roof in comparison to other building elements. A building with a large roof area in comparison to external walls, ground floors and less building services will have a significantly large impact on this credit.

Wst 01: Construction Waste Management

The aim of this credit is, “to promote resource efficiency via the effective management and reduction of construction waste.” Four credits are available, for different levels of performance. Although the roof is explicitly mentioned in this section, the impact on the waste levels is considered minimal and therefore this credit is ignored from the decision tool.

LEED

The Leadership in Energy and Environmental Design (LEED) certification system is one of the world's most widely used environmental assessment methods for buildings. There are numerous versions now in use for different building types. The following credits are identified from LEED 2009 v3 to be related to roof design and selection (US Green Building Council, 2009)

SS5.1: Site Development – Protect or Restore Habitat (1 point)

The intent of this credit is to conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity. One point is available for this credit. The attribute used to measure this is either:

1. Restore or protect a minimum of 50% of the site (excluding the building footprint) or;
2. 20% of the total site area (including building footprint), whichever is greater, with native or adapted vegetation
3. Projects earning SS Credit 2: Development Density and Community Connectivity may include vegetated roof surface in this calculation if the plants are native or adapted, provide habitat, and promote biodiversity.

SS5.2: Site Development – Maximise open space (1 point)

The intent of this credit is to promote biodiversity by providing a high ratio of open space to development footprint. One point is available for this credit. There are three cases, all of which vegetated roof areas can contribute towards compliance. The measurement is based upon three cases, which are as follows, (1) providing vegetated open space within the project boundary such that it exceeds local zoning requirements by 25%; (2) for site with no local zoning requirements to provide vegetated open space adjacent to the building, which is equal in area to the building's footprint; (3) for sites with Zoning Ordinances but no open space requirements, to provide vegetated open space equal to 20% of the total site area.

SS6.1: Stormwater Design – Quantity Control (1 point)

To limit disruption of natural hydrology by reducing impervious cover, increasing on-site infiltration, reducing or eliminating pollution from stormwater runoff and eliminating contaminants. One point is available for this credit. To achieve the credit there are two options depending on the site imperviousness.

4. *Sites with Existing Imperviousness 50% or Less*
   Implement a stormwater management plan that prevents the post development peak discharge rate and quantity from exceeding the predevelopment peak discharge rate and quantity for the 1- and 2-year 24-hour design storms or implement a stormwater management plan that protects receiving stream channels from excessive erosion. The stormwater management plan must include stream channel protection and quantity control strategies.
5. *Sites with Existing Imperviousness Greater Than 50%*
   Implement a stormwater management plan that results in a 25% decrease in the volume of stormwater runoff from the 2-year 24-hour design storm.

SS6.2: Stormwater Design—Quality Control (1 point)

The intent of this credit is, to limit disruption and pollution of natural water flows by managing stormwater runoff. One point is available for this credit.

Best Management Practice (BMP) used to treat runoff must be capable of removing 80% of the average annual post development total suspended solids (TSS) load based on existing monitoring reports. BMPs are considered to meet these criteria if:

They are designed in accordance with standards and specifications from a state or local program that has adopted these performance standards OR There exists infield performance monitoring data demonstrating compliance with the criteria.

SS7.2: Heat Island Effect—Roof

The intent of this credit is to reduce heat islands1 to minimise impacts on microclimates and human and wildlife habitats. One point is available for this credit

For low sloped roofs a SRI of greater than 78 is required for a minimum of 75% of the roof surface area. Lower, SRIs are allowed as long as the weighted average is greater than 78. Alternatively, a vegetated roof that covers at least 50% of the roof area can be used. A combination of the two approaches can also be used.

EA1: Optimise Energy Performance

The intent of this credit is to achieve increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use. Nineteen points are available for this credit, which can be awarded for different levels of performance. For new buildings, points are awarded on comparing the modelled energy performance of the building with that of a baseline building. This is done utilising building simulation. Points are awarded based on energy cost savings over the ASHRAE 90.1 baseline. The minimum performance improvement is 12% for New Buildings to achieve 1 point. For performance increments of 2% an additional point is achieved up to a maximum reduction of 48%.

The overall energy cost reductions will be significantly influenced by many factors other than the roof. However, the roof may have a large role to play in reducing energy costs through improved design. Therefore, these are included in this. This issue was not considered in the thesis written by Grant (2007). However, the focus of that thesis was purely on green roofs and excluded the application of other roof technologies or improvement in thermal performance of the roof system.

EA2: On-site Renewable Energy

To encourage and recognise increasing levels of on-site renewable energy self-supply, to reduce environmental and economic impacts associated with fossil fuel energy use. The number of points available for this credit is seven. Credits are awarded based on the percentage of energy costs that are met by renewable systems as a percentage of the building’s annual energy costs. Credits are on a minimum level of performance of 1% improvement for 1 credit in increments of 2% to 13% improvement for 7 credits. Percentage reductions are calculated against the energy performance calculated in EA1.

Whilst other factors may influence this, such as the generation of renewable energy by district systems, the roof typically provides a roof area for the installation of renewable technologies such as Solar Photovoltaics or Solar Thermal Systems. Therefore, the roof system choices could have a large influence on this credit.

Estidama

Estidama, which means sustainability in Arabic, is a relatively young sustainability rating methodology. It has been recently developed for Abu Dhabi. It is the first programme of its kind that is tailored to the Middle East region (Abu Dhabi Urban Planning Council, 2010). The influence of roof design and selection was reviewed against the credits of the rating system, as it has not yet been explicitly undertaken and documented. Additionally, the sponsoring organisation undertakes a significant proportion of their work in this region and therefore there is an industrial driver for reviewing the impact of roof choice on the achievement of credits.

The Estidama rating system is reviewed and credits relating to the design and selection of roofs are summarised. For each credit, the intent of the credit is explained, along with how performance is assessed and points awarded. The relevance of the roof selection to the achievement of the credits is also highlighted. All roof related credits are drawn out as they are likely to be environmental considerations that will inform the roof selection tool.

LBO-R3: Outdoor Thermal Comfort Strategy

The intent of this credit is, *"to increase outdoor thermal comfort during transition months and reduce thermal discomfort during summer months in public spaces and walkways.*" This is a pre-requisite credit so must be achieved to achieve other credits in Estidama. The roof is explicitly mentioned in this credit, as exterior car parking spaces, including those on roof surfaces must have a minimum of 40% shading. Additionally, canopies, which could to some extent be defined as roofs (they have a protective function), have to have a minimum Solar Reflectance Index (SRI) 29.

LBO-1: Improved Outdoor Thermal Comfort

The intent of this credit is the same as LBO-R3. However, two points are awarded for increasing the percentage of shaded areas from the pre-requisite levels. The percentages are dependent on space type, but with respect to the roof are only applicable if they are accessible public open space or if they have surface parking on them. As mentioned above in LBO-R3, shading devices must have a minimum SRI ≥ 29.

PW-2.1: Exterior Water Use Reduction

The intent of this credit is, *"to minimise landscaping water demands through effective plant selection, irrigation strategies, and promoting the use of recycled water."* Ten credits are available for this. The credit is split into 4 sections, which include:

- Plant selection (6 points)
  - 2 points for average landscape demands less than 4l/m2/day.
  - 4 points for average landscape demands less than 2l/m2/day.
- Irrigation system (1 point)
  - Available for demonstrating water efficient irrigation system has been used.
- Irrigation management system (1 point)
  - For the development of an irrigation operation and management plan.
- Recycled water (2 points)
  - 2 points must be achieved from plant selection criteria outlined above,
  - The provision of or installation of systems to allow watering using recycled water.

All the above are applicable to roofs if they are landscaped. This includes hardscape and softscape areas.

An additional 2 points are available for schools if they demonstrate that turf substitutes have been used instead of turf. However, this is less applicable to roofs.

RE-1: Improved Energy Performance

The intent of this credit is *"to promote further reductions in the projects energy consumption and hence carbon emissions associated with building operation."* Fifteen points are available for this credit and are given for improvements between 14% (1 point) and 60% (15 points) reductions in building energy consumption. This is assessed against a baseline building modelled using ASHRAE 90.1 – 2007 methodology. The scale is not linear and it becomes progressively harder to achieve points.

The roof has a part to play in improving energy performance as typically the most exposed building element to the climate. Thus improvements in thermal performance, or the use of the roof space for renewable technologies (which is further covered below) could offer a significant contribution towards this credit.

RE-2: Cool Building Strategies

The intent of this credit is, *"to determine the most effective solution to reducing a building's cooling demand by incorporating passive design strategies as a priority."* Six points are available for this credit. Five of which are available for gaining increasing reductions in annual external heat gain compared with the baseline building. Points are awarded on a linear scale from 1 point for a 10% reduction to 5 points for a 50% reduction. An additional point is available for the use of high solar reflective roofing materials, with an SRI greater than 78. Whilst the first five will be dependent on many different design improvements, the roof could play a significant part in reducing Annual External Conduction Gains, and depending on the type of roof could also influence the infiltration and solar gains.

Additionally, the reflectivity of the roof is explicitly considered in this credit. If a roof area is covered by mechanical plant, shading devices, renewable technologies, and designated vegetated roofs, then they are excluded from consideration. All exposed areas must have an SRI ≥78. However, the upper surface of any roof shading device must have a SRI ≥78.

RE-6: Renewable Energy

The intent is *"to reward projects for the use of renewable technologies, therefore reducing the carbon emissions associated with building operation and the reliance on fossil fuel based power generation."* Eight points are available for this credit. These are awarded based upon a percentage of the projects proposed energy consumption being met by renewable energy. Points are awarded from a 1 point for 1% of energy consumption met by renewable energy to a maximum of 8 points for a 20% reduction in consumption met by renewable energy. It should be noted that the scale is not linear and it gets progressively harder to achieve points.

The roof offers typically good access to the site's climatic resource. This is often the best place to put renewables on a building.

SM-2: Design for materials reduction

The intent of this credit is, *"to reduce the overall amount of material used in the development of buildings."* One point is available for this credit and is awarded based upon achieving one of three initiatives. These include two initiatives, which are not related to the roof. However, the following initiative considers the use of dual function materials and gives three options. The following two are related to roofs:

- Building Integrated Photovoltaics (BIPV), replacing traditional materials on at least 10% of the area of the building envelope (including roof)
- Vegetated roofs on at least 50% of the area of roof. Plant selection should favour native and drought-resistance species. The section of the roof must also be accessible to building users.

Therefore the roof can potentially contribute to the achievement of this credit point.

SM-4: Design for disassembly

The intent of this credit is, "to facilitate the future deconstruction and reuse of buildings and their structural and envelope components." One point is available for this credit. This involves developing a Building Disassembly Plan. Additionally, to achieve the credit the Building Disassembly Plan must demonstrate that 50% of the building structural skeleton, 75% of façade, or 90% of the roof is designed for disassembly (by surface area). The roof therefore requires significant consideration to achieve this credit.

SM-6: Design for durability

The intent of this credit is, *"to promote a long life building by protecting its components from condensation, water ingress, improper drainage and protecting vulnerable areas of the building envelope and surroundings."* One point is available for this credit. This is achieved through developing a Building Durability Plan to optimise the durability of the building envelope. This has to fulfil many requirements, which include the consideration of the lifespan of the roof.

SM-11: Rapidly Renewable Materials

The intent of this credit is, *"to increase the use of fast growing materials as an alternative to slow growing materials and finite resources."* One point is available for this credit. This can be achieved by demonstrating that:

- At least 75% by area of one or more specified building components are rapidly renewable
- At least 35% by area of two or more specified building components are rapidly renewable
- At least 15% by area of four or more specified building components are rapidly renewable

The specified building components include:

- Joinery;
- Walls and partition;
- Floors;
- Ceilings;
- **Roof.**

Therefore, this credit point could be largely influenced by the choice of roof.

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Appendix Q Green roof information tables

Reference	Research Type	Method	Study Location	Climate Type	Season	Roof buildups	Roof build up summary	Season	Main findings
Dunnett, N., A. Nagase, et al. 2008	Hydrological	**FE, LE**	Sheffield, UK	Cfb	97 - '00	The trays were filled to a depth of 100 mm with the rendzina soil	Extensive (100mm)	25 Oct - 10 Nov	In both cases, the composition of the vegetation was found to significantly affect both the amount of water retained and released from the system
Hilten, R. N., T. M. Lawrence, et al. 2008	Hydrological	**M, FE**	Athens, Georgia, USA	Cfa	Jan - Aug '05	The study site consisted of one hundred square aluminum green roof blocks3 with each block having dimensions, 60 · 60 · 10 cm. The total area for the green roof system was 37 m2. The blocks were laid on a zero-slope built-up roof above a utility room on the University of Georgia's campus. The 37 m2 area was roughly U-shaped with x-dimension of 12.3 m and y-dimension of 4.9 m. The individual blocks have three 1.0 cm diameter drains along each side approximately 1.0 cm above the base of the block. Each block was filled with engineered soil (80% expanded slate, 20% organic matter) to a depth of approximately 10 cm.	Extensive (100mm)	Annual	The study revealed that rainfall depth per storm strongly influences the performance of green roofs for stormwater mitigation, providing complete retention of small storms (<2.54 cm) and detention for larger storms, assuming the measured average moisture content (10%) as the antecedent condition.
Lin, Y.-J. and H.-T. Lin 2011	Thermal performance	**FE**	Kaohsiung, Taiwan	Aw	Jul '07 - Dec '09	100mm substrate and flourishing plants. Four substrates were used in this study. (1) sand, (2) sand with white charcoal debris (3) man mixed, decomposing organic matter (4) burned reservoir sludge.	Extensive (100mm)	19 May - 9 Jun '03 & 14 Feb - 3 Mar	Among the substrates, burned sludge has the best thermal reduction percentage of heat amplitude under the roof slab surface (up to 84.4%). Irrigation twice a week has the best thermal reduction percentage of heat amplitude (91.6%). Among the plant types, Sansevieria trifasciata cv. Laurentii Compacta and Rhoeo spathaceo cv. Compacta are found to be suitable for extensive rooftop greeneries because they have the best coverage ratio and are most drought enduring.
Simmons, M., B. Gardiner, et al. 2008	Hydrological, Thermal Performance	**FE**	Austin, Texas, USA	Cfa	Oct -Nov '06 & Mar - Jun '07	The coarse structure of the green roofs was identical across all types: membrane root barrier, drainage layer and 100 mm of substrate (growing media), however actual materials and some vertical arrangement varied among manufacturers	Extensive (100mm)	June 1 - 8	Preliminary hydrologic and thermal profile data indicated not only differences between green and non-vegetated roofs, but also among green roof designs. Maximum green roof temperatures were cooler than conventional roofs by 38°C at the roof membrane and 18°C inside air temperature, with little variation among green roofs. Maximum run-off retention was 88% and 44% for medium and large rain events but some green roof types showed very limited retention characteristics.
Teemusk, A. and Ü. Mander 2007	Hydrological	**FE**	Tartu, Estonia	Dfb	Jun '04 - Apr '05	a modified bituminous base roof, a plastic wave drainage layer (8 mm), rock wool for rainwater retention (80mm) and a substrate layer (100mm) with LWA (66%), humus (30%) and clay (4%). The reference roof is a modified bituminous membrane roo	Extensive (100mm)	13 Jun - 17 Aug '00	The studied greenroof effectively retained light rain—the retention for 2.1mmrainfallwas 85.7%. In the case of a heavy rainstorm (12.1 mm), the greenroof can delay the runoff for up to half an hour, but cannot fully retain it—the runoff volume was the same as that of the reference roof.
Teemusk, A. and Ü. Mander 2009	Thermal performance	**FE**	Tartu, Estonia	Dfb	Jun '04 - Apr '05	**Green roof** (a modified bituminous baseroof, a plastic wave drainage layer (8mm), rock wool for rain water retention (80mm) and a substrate layer (100mm) with LWA (66%), humus (30%) and clay (4%). **Bitumen** (The reference roof is a modified bituminous membrane roof	Extensive (100mm)	Summer season?	In the summer period, the100-mm-thick substrate layer of the green roof significantly decreased temperature fluctuations compared with the bituminous roof surface. In autumn and spring the substrate layer protected the base roof's membrane from rapid cooling and freezing. It also provided effective thermal insulation in winter. In addition, measurements showed that the surface of the LWA media in the green roof heats and cools more than the surface of the bituminous roof; however, its influence on temperature in the substrate layer was not considerable. Indexes to characterize greenroof's temperature effects are proposed

Reference	Research Type	Method	Study Location	Climate Type	Season	Roof buildups	Roof build up summary	Season	Main findings
Teemusk, A. and Ü. Mander 2010	Thermal performance	**FE**	(1) Tartu, Estonia (2) Talin, Estonia	Dfb	June '04 - Dec '07	Green roof consists of the following layers: amodified bituminous base roof, a plastic wave drainage layer, rock wool for rainwater retention (80mm) and a substrate layer (100mm) with LWA (66%), humus (30%) and clay (4%). SOD roof On the base flooring there is a modified bituminous membrane layer, a plastic wave drainage layer and a soil layer (120mm) with a transplant layer (20–30 mm). Thus the roof is a 150-mm-thick turf roof, more often referred to as a sod roof, as in this article. Modified bitumen & Steel Sheet	Extensive (100mm)	4 Sep - 12 Dec '02	In summer, temperatures under both the green roof (100mm) and the sod roof (150mm) showed a similar temperature run; undesirable higher temperatures on the surfaces did not cause a notable increase in temperature under the substrate layers. The difference between the temperature amplitude under the substrate layers of the planted roofs and the surfaces of the conventional roofs was on average 20 ◦C. In autumn and spring, the sod roof's soil layer showed higher temperatures and lower amplitude than the green roof's substrate layer, which cooled more. In winter, temperatures under the substrate layers of the planted roofs were higher than the surfaces of the conventional roofs; average amplitude was 1 ◦C and 7–8 ◦C, respectively.
Gregoire, B. G. and J. C. Clausen 2011	Hydrological	**FE, LR**	Storrs, USA	Dfb	Jan 25 '09 - Feb 1 '10	Extensive Green Grid ® modules, a rootbarrier / filter fabric that was overlain with 10.2 cm of growth media that consisted of 75% lightweight expanded shale, 15% composted biosolids, and 10% perlite. Each module was planted with a mixture of 10 Sedum species.	Extensive (102mm)		The green roof water shed retained **51.4%** of precipitation during the study period based on area extrapolation. Overall, the green roof retained **34%** more precipitation than predicted by the paired watershed calibration equation.TP and PO4–P mean concentrations in green roof runoff were higher than in precipitation but lower than in runoff from the control. Overall, the greenroof was effective in reducing stormwater runoff and overall pollutant loading for most water quality contaminants
Alexandri, E. and P. Jones 2007	Thermal performance	**M, FE**	Cardiff, Wales	Cfb	Aug '04 (5 days)	0.01m of soil, 0.01m of grass	Extensive (10mm)		Special attention is given to the comparison between the experimental results and the outputs of only heat transfer algorithms and heat and mass transfer expressions. Taking these comparisons into consideration, conclusions are drawn about developing an accurate algorithm describing the thermal effect of green roofs on the built microclimate.
Theodosiou, T. G. 2003	Thermal performance	**M, FE**	Thessaloniki, Greece	Csa	23 Jul - 13 Aug	Canopy layer (0.3m), soil (0.120m), filter (0.003m), Drainage (0.006m), Bitumen root protection (0.004m), lightweight concrete (0.050m), insulation (0.050m), Water vapour barrier, concrete slab (0.150m), roof plaster (0.015m)	Extensive (120mm)	Jul '09 (11 days)	The results are validated by the use of real data taken from an existing construction in the Mediterranean area and a parametric study is performed in order to evaluate the main planted roof characteristics that affect the performance of a planted roof as a passive cooling technique. The most important parameter, when considering vegetation, is the foliage density, which in the model is represented by the leaf area index. According to the analytical model, transpiration and shading are influenced by it. LAI influences most of the cooling effects a planted roof can provide. The greater the foliage density is, the bigger the total leaf area—where transpiration occurs—is. In addition, large parameter values like six offer practically complete shading to the lower foliage area and the soil layer surface, protecting it from solar irradiation. Climatic conditions prove to play an important role in the performance of planted roofs as a cooling technique. Despite the fact that these parameters were studied separately, a less realistic approach, it was shown that relative humidity is the most important climatic factor. This is true not only for planted roofs, but for all the techniques that are related to evaporation. A dry environment enhances evaportranspiration and cooling capabilities. Wind speed has the same effect, though not as strong as relative humidity. Higher values offer improved vapour removal from the foliage volume and leads to increased evaportanspiration

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Schroll, E., J. Lambrinos, et al. 2011	Hydrological	**FE**	Oregon, USA	Csb	12 Nov - 24 Apr & 25 Jun - 21 Oct	Drainage layer and medium in addition to the impervious membrane. The drainage layer consisted of 6.35mmthick standard drainage mat with a geocomposite fabric bonded to one side, placed up to provide a filter fabric between media and drainage layer (Tremco, Ashland, Ohio). Growing medium was a typical extensive green roof (PRO-GRO Mixes Inc, Tualatin, Oregon). Medium was composed primarily of screened pumice (0.16–0.95 cm), with minor percentages of Fiber Life Compost and paper fiber. Medium was uniformly applied to a depth of 12.7 cm.	Extensive (127mm)	Jan - Aug '05	During the winter rainy season vegetation had no significant influence on stormwater retention; medium-only and vegetated roofs reduced stormwater runoff nearly identically relative to the impervious roofs. In contrast, during summer vegetated roofs retained significantly more rainfall than medium-only roofs, although this effect depended strongly on the size of the rain event. These results suggest that cool wet season climates such as the Pacific Northwest are challenging ones for green roof stormwater performance. In order to optimize stormwater benefits of green roofs, designers should create explicitly regional designs that include plant selections better matched to the specific environmental and management constraints.
Parizotto, S. and R. Lamberts 2010	Thermal performance	**FE**	Florianópolis, Brazil	Cfa	1 -7 Mar '08 & 25 - 31 May '08	vegetation (200mm) soil substrate (140mm) geotextile filter (10mm) gravel and pebble drainage layer (180mm) reinforced mortar (30mm) extruded polystyrene insulation (20mm) no asphalt sealer (4mm) concrete slab (150mm)	Extensive (140mm)	Aug - Sep '02; Jun - Jul '03; Feb - Mar '04	During the warm period, the green roof reduced heat gain by 92 to 97% in comparison to ceramic and metallic roofs, respectively, and enhanced the heat loss to 49 and 20%. During the cold period, the green roof reduced heat gain by 70 and 84%, and reduced the heat loss by 44 and 52% in comparison to ceramic and metallic roofs, respectively.
Takakura, T., S. Kitade, et al.	Thermal performance	**FE, M**	Tokyo, Japan	Cfa	Summer '93 (3 days)	Roof build up well labelled, 140mm of soil on a 60mm concrete roof (ivy 150mm approx; turn 75 mm approx)	Extensive (140mm)	Jul '07 - Dec '09	LAI up to 3 can significantly increase the cooling effect on the air space. A simulation model was developed, and the effect of evapotranspiration was taken into account. The simulated results agreed fairly well with measured values when evapotranspiration was not large, but there was some difference at high evapotranspiration rates.
Beck, D. A., G. R. Johnson, et al. 2011	Hydrological	**LE**	N/A	N/A	N/A	Trays: Henry DB-50 greenroof drainage membrane: Soil in the form of either of either Pro-Gro extensive mix (green roof growing media that contains a mix of gravel, sand, silt, clay, as well as specially screened pumice, Fiber Life compost, and paper fiber), or Pro-Gro extensive mix containing 7% weight by weight biochar, was added to an initial depth of **15 centimeters**.	Extensive (150mm)	8-31 Aug '91	Addition of biochar to the soil resulted in an approximate 4.4% increase inwater retention by trays containing close-to-saturated soil.
Ondimu, S. N. and H. Murase 2007	Thermal performance	**LE, M**	?? ,Japan	N/A	N/A	18.1mm Moss mat (Sunagoke moss supported in a polyvinyl chloride (PVC) netting)	Extensive (18.1mm)	1 -7 Mar '08 & 25 - 31 May '08	The effective thermal conductivity of the material was 0.1 Wm-1K-1 1at 0%; 0.24 at 50% and 0.28 at 100% water contents (db). Nodal temperature profiles showed that the material exhibits steady-state heat transfer at 0% and 100% water contents (db) and transient-state heat transfer at water contents in between. It was concluded that inverse finite-element modelling is a feasible alternative technique for evaluating the thermal conductivity of living roof.

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VanWoert, N. D., D. B. Rowe, et al. 2005	Hydrological	**FE**	Michigan, USA	Dfa/Dfb	28 Aug '02 · 31 Oct '03	Two of the three self-contained sections on each platformused the Xero Flor XF108 drainage layer (Wolfgang Behrens Systementwicklung GmbH, Groß Ippener, Germany) installedover the Teranap Waterproofing System(Fig. 2). The drainage layer consisted of a geotextile fabric with nylon coils attachedon the underside. The total thickness of this layer was approx-imately 1.5 cm. For additional water holding capacity, a 0.75-cm-thick water retention fabric (Xero Flor XF158) capable ofretaining up to 1200 g m 2 of water was placed over the drainagelayer. The water retention fabric was composed of a recy-cled synthetic fiber mixture consisting of polyester, polyamide,compolypropylene, and acrylic fibers. Above this additional re-tention fabric was the vegetation carrier (Xero Flor XF301),which included a recycled synthetic fiber fabric similar toXF158 used for water retention sewn to an inverted layer ofXF108 that held media and vegetation. This water retentionplatlayer could hold up to 800 g m 2 of water and was approx-imately 0.75 cm thick. There was then 2.5 cm of growing media have the potential to hold up to 7 mm of rainfall (Table 1). Total thickness of the drainage layer, vegetation carrier, and growing media was approximately 5.5 cm. The systemas a whole permits water exceeding the holding capacity of the retention fabric and plant- ing media to drain through the nylon coils and exit the roof.	Extensive (25mm)	Annual	Overall, mean percent rainfall retention ranged from 48.7% (gravel) to 82.8% (vegetated). The second study test the influence (2% and 6.5%) and green roof media depth (2.5, 4.0 and 6.0cm) on stormwater retention. For all combined rain events, planforms at 2% slope witha 4cm media depth had the greatest mean retention, 87%, although the difference from the other treatments was minimal. The combination of reduced slope and deeper media clearly reduced the total quantity of runoff. For both studies vegetated green roof systems not only reduced the amount of stormwater runoff, they also extended its duration over a period of time beyond the actual rain event.
Onmura, S., M. Matsumoto, et al. 2001	Thermal performance	**FE, M, LE**	Osaka, Japan	Cfa	8-31 Aug '91	15cm concrete slab, 8cm top mortar and an asphalt membrane waterproofing layer. Total thickness of lawn fabric layer including the drainage layer and the oot intercepting layer was about 8cm. The thickness of the lawn was about 3cm	Extensive (30mm)	Oct -Nov '06 & Mar - Jun '07	The roof surface tempearture decreased from about 60 to 30 deg C during the day time, which was estaimated to be followed by a 50% reduction in heat flux into the room by simple calculations.
Villarreal, E. L., A. Semadeni-Davies, et al. 2004	Hydrological	**M**	Malmo, Sweden	Dfb	Annual		Extensive (30mm)	Summer '93 (3 days)	Direct runoff was simulated using the time–area method; and routing through the BMPs using PondPack. As the BMPs are in series, the outflow of one BMP became part of the inflow to the next in the system. Additionally, the water balance for the year 2001–2002 was investigated. It was found that the green-roofs are effective at lowering the total runoff from Augustenborg and that the ponds should successfully attenuate storm peak flows for even the 10-year rainfall.

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He, H. and C. Y. Jim 2010	**Thermal performance**	**M, FE**	Hong Kong	Cwa	Annual (2 years)	Soil 35 - 80mm Vegetation height 40 - 700mm	Extensive (35-80mm)	Aug & Nov. '04	The proposed model is tested and validated to be efficient to simulate solar energy transmission in green roofs, with some major findings. Firstly, the solar radiation transmission processes might be considered as free vibration motion. Daytime positive heat storage of the green roof is 350–520W·m−2 on an hourly basis. Nighttime or afternoon negative value registers a rather constant magnitude of −60W·m−2. Daily net average is positive around 155–210W·m−2. Secondly, solar radiation vibration is highly correlated with plant structure. The canopy reflectance and transmittance are strongly correlated (R2 = 0.87). The multilayer shrub treatment has the highest shield effectiveness (0.34), followed by two-layer groundcover (0.27), and single-layer grass (0.16). Green roof vegetation absorbs and stores large amounts of heat to form an effective thermal buffer against daily temperature fluctuation. Vegetated roofs drastically depress air temperature in comparison with bare ground (control treatment). Finally, the thermodynamic model is relatively simple and efficient for investigating thermodynamic transmission in green roof ecosystem, and it could be developed into a broad solar radiant land cover model.
Jim, C. Y. and H. He 2010	**Thermal performance**	**FE**	Hong Kong	Cwa	Annual		Extensive (35-80mm)	Aug '04 (5 days)	The results demonstrated the life cycle characteristics of heat flux components. The dynamic changes of sensible (H), latent (E) and soil (G) heat fluxes were denoted by single-peak quadratic curves. Net radiation (Rn) was largely determined by quantity and variation trends of E, reaching at 1300 h a maximum E of 655Wm−2 and maximumHof 369Wm−2. Temporal heat-flux fluctuations were strongly correlated with meteorological variables. Extreme values of H and E correlated well with precipitation and temperature (R2 = 0.78). Dynamics of heat-flux magnitude and partitioning demonstrated notable differences by daily and season periods. They displayed considerable variations in flux partitioning, with Bowen ratios strongly correlated with weather conditions and vegetation types. The energy budget of the green roof ecosystem is unbalanced with a heat loss of about 15.5% caused by soil and canopy heat reserve.
Feng, C., Q. Meng, et al 2010	**Thermal performance**	**M, FE**	Guangzhou, China	Cfa	Jul '09 (11 days)		Extensive (40mm)	97 - '00	Experimental results demonstrated that within 24 h of a typical summer day, when soil was rich in water content, solar radiation accounted for 99.1% of the total heat gain of a Sedum lineare green roof while convection made up 0.9%. Of all dissipated heat 58.4% was by the evapotranspiration of the plants–soil system, 30.9% by the net long-wave radiative exchange between the canopy and the atmosphere, and 9.5% by the net photosynthesis of plants. Only 1.2% was stored by plants and soil, or transferred into the room beneath.
Villarreal, E. L. and L. Bengtsson 2005	**Hydrological**	**FE**	Lund, Sweden	Dfb	Jul - Aug '03	a soil-vegetation layer of 4 cm and an underlying geotextile layer. The soil was composed of 5% crushed limestone, 43% crushed brick, 37% sand, 5% clay and 10% organic material. When dry, the total weight of the green-roof was 35 kg/m2 and the soil porosity was 70%. The experiments were carried out for different slopes (2◦, 5◦, 8◦ and 14◦) under both dry (7 summer days without precipitation between experiments, during July–August 2003) and wet initial conditions (i.e., at field capacity).	Extensive (40mm)	Spring '06	The obtained UH was able to accurately predict peak flows and runoff volumes for any rain input. Results from the experiments indicated that roof slope had no effect on the direct runoff hydrograph, i.e., on peak flows and stormwater volumes. Whether conditions were dry or wet affected the retention capacity of the green-roof; for dry conditions, between 6 and 12mm of rain were required to initiate runoff, while for wet conditions the response was almost straight.

Reference	Research Type	Method	Study Location	Climate Type	Season	Roof buildups	Roof build up summary	Season	Main findings
Voyde, E., E. Fassman, et al. 2010	Hydrological	**FE**	Auckland, New Zealand	Cfb	Annual	50-70mm with different locally sourced substrates	Extensive (50-70mm)	Annual	No statistically significant differences in runoff response were found between the three substrate types tested or the two different depths. The cumulative retention efficiency of the living roof was 66% based on 12 months of continuous monitoring. On an event basis, the living roof demonstrated reductions in both volume and peak flow rates regardless of the rainfall and climatic characteristics. The living roof retained a median of 82% of rainfall received per rainfall event, with a median peak flow reduction of 93% compared to rainfall intensity. The hydrologic response of a living roof is controlled by multiple parameters such as rain depth, rain intensity, climatic variables and antecedent dry days. Detailed analysis indicates that antecedent dry days have the greatest influence on retention. Seasonal differences do not influence runoff response; living roofs will effectively moderate runoff hydrology year round in Auckland's sub-tropical climate.
Jim, C. Y. and S. W. Tsang 2011	Thermal performance	**M, FE**	Hong Kong	Cwa	Mar '08 (18 months)	(1) Soil 50; (2) Soil 50, drainage 25mm; (3) Soil 50, drainage 25, rockwool 40mm	Extensive (50mm)	N/A	The model remains robust despite seasonal and weather variabilities. Our research findings contradict with some researches in the temperate region that the thermal dissipation in greenroofs with dense vegetation is lower than thermally insulated bareroofs"
Getter, K. L., D. B. Rowe, et al. (). 31(4): 225-231. 2007	Hydrological	**FE**	Michigan , USA	Dfa/Dfb	26 Apr '05 - 1 Sep '06	Total thickness of the drainage layer, vegetation carrier, and growing media was approximately 5.5 cm.	Extensive (55mm)	23 Jul - 13 Aug	Data demonstrated an average retention value of 80.8%. Mean retention was least at the 25% slope (76.4%) and greatest at the 2% slope (85.6%). In addition, runoff that did occur was delayed and distributed over a long period of time for all slopes. Curve numbers, a common method used by engineers to estimate stormwater runoff for an area, ranged from 84 to 90, and are all lower than a conventional roof curve number of 98, indicating that these greened slopes reduced runoff compared to traditional roofs
MacIvor, J. S. and J. Lundholm 2011	Hydrological, Thermal Performance	**FE**	Halifax, Nova Scotia, Canada	Dfb	May - Oct '09	6cm depth of various types of substrate	Extensive (60mm)		Over the growing season, the top performing species reduced roof surface temperature by an average of 3.44 ◦C and increased solar reflectivity by 22.2% over the growing medium only controls. Moreover, the best species retained 75.3% of experimentally added stormwater. Our results demonstrate that several species (mainly graminoids) performed better than creeping shrubs and forbs for most functions, although significant variation existed within life-form groups.
Carter, T. and C. R. Jackson 2007	Hydrological	**M, FE**	Athens, Georgia, USA	Cfa	Annual	Blend of 55% Stalite expanded slate, 30% USGA sand, and 15% organic matter with a bulk density of 1.508 g/cm3 and the total porosity is 50.6%. The soil mix was spread to a depth of 7.62 cm across the plot. Six drought-tolerant plant species included Sedum album "Murale", Sedum album "Jellybean", Sedum kamtschaticum, Sedum sexangulare, Delosperma nubigenum, and Delosperma cooperi. The plants were 3.4 cm×3.4 cm×6.25 cm plugs which were planted in the growing media at a density of 50 plants/m2.	Extensive (76mm)	12 Nov - 24 Apr & 25 Jun - 21 Oct	Hydrologic modeling demonstrated that widespread green roof implementation can significantly reduce peak runoff rates, particularly for small storm events.

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Carter, T. L. and T. C. Rasmussen 2006	Hydrological	**FE**	Athens, Georgia, USA	Cfa	Annual	This soil mix is a blend of 55 percent Stalite expanded slate, 30 percent United States Golf Association sand, and 15 percent composted organic matter composed primarily of worm castings. This medium has a bulk density of 1.508 g/cm3, and the total porosity is 50.6 percent. The soil mix was spread to a depth of 7.62 cm across the plot. Six drought tolerant plant species were selected for their ability to survive low nutrient conditions and extreme temperature fluctuations found at the roof surface. The species included Sedum album "Murale," Sedum album "Jellybean," Sedum kamtschaticum, Sedum sexangulare, Delosperma nubigenum, and Delosperma cooperi. The plants were supplied as 3.4 by 3.4 by 6.25 cm plugs, which were planted in the growing medium at a density of 50 plants/m2.	Extensive (76mm)	Annual (2 years)	Green roof precipitation retention decreased with precipitation depth; ranging from just under 90 percent for small storms (<2.54 cm) to slightly less than 50 percent for larger storms (>7.62 cm). Average runoff lag times increased from 17.0 minutes for the black roof to 34.9 minutes for the green roof, an average increase of 17.9 minutes. Precipitation and runoff data were used to estimate the green roof curve number, CN = 86.
Stovin, V. 2010	Hydrological	**FE**	Sheffield, UK	Cfb	Spring '06	The test bed (3.1m) (Fig. 3) uses a standard commercial (Alumasc/Zinco) extensive green roof system, comprising a sedum vegetation layer growing in 80mm of substrate. The basic configuration is as shown in Fig. 2. The base of the rig is laid at a slope of 1.51. The substrate is composed of a mixture of crushed brick and fines. A fine particle filter membrane separates the substrate from the underlying FloraDrain FD25 'egg box' drainage layer. The drainage layer alone has a nominal retention capacity of 3 L/m2 (i.e. 3mm rainfall).	Extensive (80mm)	Annual	Tthe average volume retention was 34% and the average peak reduction was 57%. The key hydrological determinants were the antecedent dry weather period (ADWP), mean rainfall intensity and rainfall depth. Detailed examination of rainfall–runoff relationships in summer 2007 demonstrates the dependency of performance on antecedent moisture conditions
Ayata, T., P. C. Tabares-Velasco, et al. 2011	Thermal performance	**LE, M**	Pennsylvania , USA	N/A	N/A		Extensive (90mm)	Mar '08 (18 months)	The study proposed a "basic model" for calculations of the convective heat transfer at green roof assemblies, which is a modified version of the Newton's cooling law, calibrated and then validated with different sets of data.
Köhler, M. and P. H. Poll 2010	Hydrological	**FE**	Berlin, Germany		1960 - present		Extensive (Unclear)	28 Aug '02 - 31 Oct '03	Regarding the growing media, we could show that total porosity rises over a period of 10 years from 50 to 60%. In the meantime C/N-ratio falls from initially 25 down to 13.
Mentens, J., D. Raes, et al. 2006	Hydrological	**LR, M**	Germany	Cfb / Dfb/Dfc	N/A		Extensive (varies)	26 Apr '05 - 1 Sep '06	The derived empirical models allowed us to assess the surface runoff from various types of roofs, when roof characteristics and the annual or seasonal precipitation are given. The annual rainfall–runoff relationship for green roofs is strongly determined by the depth of the substrate layer. The retention of rainwater on green roofs is lower in winter than in summer. The application of the derived annual relationship for the region of Brussels showed that extensive roof greening on just 10% of the buildings would already results in a runoff reduction of 2.7% for the region and of 54% for the individual buildings. Green roofs can therefore be a useful tool for reducing urban rainfall runoff. Yet in order to provide a greater effect on overall runoff they should be accompanied by other means of runoff reduction and/or water retention.
Pearlmutter, D. and S. Rosenfeld, 2008	Thermal performance	**FE**	Be'er Sheva, Negev, Israel	Bsh	Summer season?	16cm layer of soil 10cm concrete roof	Intensive (160mm)	Jan 25 '09 - Feb 1 '10	Covering a building's roof with soil, wetting the soil and shading the wet soil surface may provide a simple and efficient means of low-energy cooling in hot and dry climates – has been largely confirmed under the conditions of the experiment.

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Sailor, D. J. 2008	**Thermal performance**	**M, FE**	Florida, USA	Cfa	Annual	Values of key model input parameters were as follows: height of plants = 0.5 m; LAI = 5.0; media thickness = 0.18 m; conductivity = 0.4 W/m K; specific heat = 1100 J/kg K; and media density = 641 kg/m3.	Intensive (180mm)	May - Oct '09	These tests focus on evaluating the role of growing media depth, irrigation, and vegetation density (leaf area index) on both natural gas and electricity consumption. Building energy consumption was found to vary significantly in response to variations in these parameters. Building energy consumption was found to vary significantly in response to variations in these parameters. **Further, this response depended significantly on building location (climate).**
Fioretti, R., A. Palla, et al. 2010	**Hydrological Thermal**	**FE**	(1) North West Italy, (2) Central Italy	Csa / Csb		Not comprehensive data for the roof at Marche Polytechnic University A protection layer (300 gr/m2 non woven), a drainage layer (realized by lapillus for a depth of 15 cm), a filter layer (100 gr/m2 non woven fabric) and a growing medium with mixed soil (lapillus, pumice, zeolite and 200 l/m3 of peat) for a depth of 20 cm. In one half the growing medium is 70% lapillus, 30% pumice and peat and in the other half the composition is 70% lapillus, 20% pumice, 10% zeolite and peat.	Intensive (200mm)	Jun '04 - Apr '05	As for water management, it is confirmed that green roofs significantly mitigate storm water runoff generation e even in a Mediterranean climate in terms of runoff volume reduction, peak attenuation and increase of concentration time.
Lazzarin, R. M., F. Castellotti, et al. 2005	**Thermal performance**	**FE, M**	Vicenza, Italy	Cfa	Aug - Sep '02; Jun - Jul '03; Feb - Mar '04	The green roof consists of a 20 cm soil layer over an 11 cm drainage layer made of expanded polyethylene. The greenery is a kind of sedum, grown from premixed seed in the soil.	Intensive (200mm)	Jun '04 - Apr '05	The outside air conditions are reported in the graph of Fig. 5: in dry conditions the temperature at the surface reached even 55 degC and so the outgoing adduction flux (24 units) was higher than the corresponding one in wet conditions (13 units) when the surface temperature exceeded 40degC only once. On the other hand, the wet soil gave rise to an evapotranspiration of 25 units whereas in dry conditions that contribution was limited to 12 units. This changed role between adduction and evapotranspiration produced a different thermal conduction towards the lower layer: in wet conditions the units were reduced by 80% with respect the dry conditions (Fig. 4).
Wong, N. H., Y. Chen, et al. 2003	**Thermal performance**	**FE**	Singapore	Af	Oct - Nov	Roof build up information given… 3 types: (1) Exposed roof slab (2) 200mm soil (3) 200mm soil + vegetation	Intensive (200mm)	June '04 - Dec '07	Without plants, the maximum temperature of the hard surface could reach around 57◦C when solar radiation was at around 1400 W=m2 during afternoon (see Figs. 8 and 9). The maximum daily variation of surface temperature was around 30◦C. For bare soil, the surface temperature measured during daytime was not as high as that of the hard surface. The maximum surface temperature of bare soil was around 42◦C and the maximum daily variation of surface temperature was around 20◦C. With the presence of vegetation, the surface temperature was further reduced. The results shows that the shading e>ect of plants is highly dependent on the LAIsince higher temperatures were usually found under sparse foliages (A, C, and F) while lower temperatures were detected under dense ones (B, D, and E)
Takebayashi, H. and M. Moriyama 2007	**Thermal performance**	**FE**	Kobe, Japan	Cfa	Aug & Nov. '04	21cm depth of soil, 4.2cm water content slab, 20cm concrete slab Bare soil, green lawn, Concrete, Highly reflective white paint, highly reflective grey paint	Intensive (210mm)	Jul - Aug '03	In the daytime, the temperature of the cement concrete surface, the surface with highly reflective gray paint, bare soil surface, green surface and the surface with highly reflective white paint are observed to be in descending order. On a surface with highly reflective white paint, the sensible heat flux is small because of the low net radiation due to high solar reflectance. On the green surface, the sensible heat flux is small because of the large latent heat flux by evaporation, although the net radiation is large. On the cement concrete surface and the surface with a highly reflective gray paint, the sensible heat fluxes have almost the same values because their solar reflectance is approximately equal.

Reference	Research Type	Method	Study Location	Climate Type	Season	Roof buildups	Roof build up summary	Season	Main findings
Barrio, E. P. D. 1998	Thermal performance	**M**	Cedex, France	N/A	N/A		Intensive / Extensive (100 - 300mm)	Annual	Green roofs do not act as cooling devices but as insulation ones, reducing the heat flux through the roof. A relatively small set of parameters have been identified as relevant for green roof design: the leaf area index (LAI) and the foliage geometrical characteristics, the soil apparent density, its thickness, and its moisture content.
Eumorfopoulou, E. and D. Aravantinos 1998	Thermal performance	**M**	Thessaloniki, Greece.	N/A	N/A		Intensive / Extensive (50 - 900mm)	24 hour	Planted roof elements with different heights of plants and different drainage layers are calculated and a comparison between a bare roof and a planted roof is made. All sections are calculated with and without thermal insulation. The results are illustrated in figures. in which the temperature of the layers of the planted roof is presented for both winter and sumnmer. The planted root' contrihules ti) the thermal protection of the building. but does not replace the thermal insulation layer.
Bowler, D. E., L. Buyung-Ali, et al. 2010	Thermal performance	**LR**	N/A	N/A	N/A		N/A	N/A	Meta-analysis show that, on average, a park was 0.94 ◦C cooler in the day. However, evidence for the cooling effect of green space is mostly based on observational studies of small numbers of green sites.
Castleton, H. F., V. Stovin, et al. 2008	Thermal performance	**LR**	Sheffield, UK	N/A	N/A	N/A	N/A	N/A	Review
Czemiel Berndtsson, J. 2010	Hydrological	**LR**	Lund, Sweden	N/A	N/A	N/A	N/A	N/A	Review
Rowe, D. B. 2010	Hydrological	**LR**	N/A	N/A	N/A	N/A	N/A	N/A	Future directions for research include plant selection, development of improved growing substrates, urban rooftop agriculture, water quality of runoff, supplemental irrigation, the use of grey water, air pollution, carbon sequestration, effects on human health, combining green roofs with complementary related technologies, and economics and policy issues.
Alexandri, E. and P. Jones 2008	Thermal performance	**M**	Athens, Greece & Cardiff, Wales	N/A	24 hour		Unclear	N/A	It has been shown that there is an important potential of lowering urban temperatures when the building envelope is covered with vegetation. Air temperature decreases at roof level can reach up to 26.0 1C maximum and 12.8 1C day-time average (Riyadh), while inside the canyon decreases reach up to 11.3 1C maximum and 9.1 1C daytime average, again for hot and arid Riyadh.
Kumar, R. and S. C. Kaushik 2005	Thermal performance	**M, FE**	Yamuna Nagar, India	Bsh	Jun	No comprehensive build up informatinon… missing values and difficult to believe values	Unclear	N/A	The model is found to be very accurate in predicting green canopy-air temperature and indoor-air temperature variations (error range 73.3%, 76.1%, respectively). Cooling potential of green roof is found adequate (3.02kWh per day for LAI of 4.5) to maintain an average room air temperature of 25.7 1C. The present model can be easily coupled to different greenhouse and building simulation codes.
Niachou, A., K. Papakonstantinou, et al. 2001	Thermal performance	**FE, M**	Athens, Greece	Bsh	Jun - Aug	No good data on roof build up	Unclear	N/A	During a typical summer day lower indoor air temeprature is measured in the building with the green roof, with dense sampels of measurements not exceeding the value of 30 degC, in periods where the air conditioning systems were not operating. On the contrary, in the building with the green roof, the air temperature was exceeding a 30 degC value and the daily temperature width was also higher. In the case of the non-insulated roofs with and without the green roof, the estimated differences of the heat transfer coefficient varied from 6 - 16W/m2K. Finally for well-insulated roofs the differences of the heat transfer coefficients are much lower ranging from 0.02 to 0.06 W/m2K. As a results the heat insulation performance of the green roof becomes considerable in constructions with low or no insulation.

Reference	Research Type	Method	Study Location	Climate Type	Season	Roof buildups	Roof build up summary	Season	Main findings
Sailor, D. J., D. Hutchinson, et al. 2008	Thermal performance	**LE**	Lab based experiments	N/A	N/A	unknown, but just substrates	Unclear	N/A	The results indicate significant variability in properties as a function both of soil composition and soil wetness. Thermal conductivity ranged from 0.25 to 0.34 W/(m K) for dry samples and 0.31–0.62 W/(m K) for wet samples. Specific heat capacity ranged from 830 to 1123 J/(kg K) for dry samples and 1085–1602 J/(kg K) for wet samples. Albedo was consistently higher for dry samples (0.17–0.40) decreasing substantially (0.04–0.20) as moisture was added. Thermal emissivities were relatively constant at 0.96 0.02 regardless of soil type or moisture status.
Santamouris, M., C. Pavlou, et al. 2007	Thermal performance	**FE, M**	Athens, Greece	Bsh	4 Sep - 12 Dec '02	Unclear	Unclear	N/A	The energy performance evaluation showed a significant reduction of the building's cooling load during summer. This reduction varied for the whole building in the range of 6–49% and for its last floor in the range of 12–87%. Moreover, the influence of the green roof system in the building's heating load was found insignificant, and this can be regarded a great advantage of the system as any interference in the building shell for the reduction of cooling load leads usually to the increase of its heating load.
Wong, N. H., D. K. W. Cheong, et al. 2003	Thermal performance	**M**	Singapore	Af	Annual	not clear	Unclear	N/A	The results showed that the installation of rooftop garden on the five story commercial building can result in a saving of 0.6-14.5% in the annual energy consumption. Shrubs were found to be most effective in reducing building energy consumption. The calculated R-values of turfinig, shrubs and trees are 0.36, 1.61 and 0.57 respectively. Calculated from summer results
Wong, N. H., P. Y. Tan, et al. 2007	Thermal performance	**FE**	Singapore	Af	May - Jun & Feb - Mar	Information on the type of roof build up is not available	Unclear		The green roof tends to experience lower surface temperature than the original exposed roof surface, especially in areas well covered by vegetation. A maximum temperature difference of 18degC was observed. In areas that tend to be sparsely covered by vegetation, the peak temperature recorded was up to 73.4 degC during the day time. Ambient air temperature, correspondingly, at 300mm above the substrate surface can reach 40 degC.The heat flux through the roof structure was greatly reduced due to the installation of extensive systems. Maximally, over 60% of heat gain was stopped by the system.
Fang, C.-F. 2008	Thermal performance	**FE, LE**	Taiping City, Taiwan	N/A	N/A			1960 - present	Thermal reduction effect of plant layers on rooftops through experiments performed in a controlled environment. The relevant parameters are coverage ratio (CR) and total leaf thickness (TLT). Both parameters are positively correlated with thermal reduction ratio (TRR).